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Assessment of Electricity Storage Technology for Solar PV

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Unless otherwise specified, the sources of figures and tables in this report are from the results of the study.

Disclaimer

This report was prepared based on the results of the Workshop entitled 'Assessment of Electricity Storage Technology for Solar PV', an initiative of the Economic Research Institute for ASEAN and East Asia (ERIA). Participants of the workshop contributed to the study based on their personal expertise and observations rather than as a national delegate of their respective countries. This study was not intended to be used for commercial or business purposes. Rather, it aims to deliver policy implications from an academic viewpoint. It is not meant to represent the position or opinions of ERIA or its members, or the official position of any staff members.

Foreword

Solar photovoltaic (PV) is one of the promising technologies to address not only climate issues but pollution and energy security concerns as well. The rapidly declining cost of solar PV systems makes it an even economically feasible choice for a country. However, it is also a fact that on-grid solar PV is beset with unresolved issues such as fluctuating power output. In terms of the choice of technologies, we already have existing alternatives such as lithium-ion batteries. In choosing the most appropriate technology, however, cost is one of the biggest considerations. This issue is well known but has not been well quantified. Hence, this study tries to quantify the necessary capacity of batteries against the output from solar PV, as well as their estimated total system costs. The cost estimates based on varied assumptions will help policymakers create better energy policies in their respective ASEAN countries.

Ichiro Kutani

Project Leader

June 2018

Acknowledgement

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Ichiro Kutani
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June 2018

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List of Abbreviations and Acronyms

ASEAN	Association of Southeast Asian Nations
CAES	compressed air energy storage
CAPEX	capital expenditure
EPNS	Energy Projects of National Significance
FiT	feed-in-tariff
GW	gigawatt
GWh	gigawatt-hour
Li-ion	Lithium-ion
IGS	intermittent generation sources
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelised cost of electricity
MW	mega watt
MWac	mega watt alternating current
MWp	mega watt peak
PDP	power development plan
PLN	Perusahaan Listrik Negara
PPA	power purchase agreement
PSH	pumped storage hydro
RE	renewable energy
REC	Renewable Energy Certificate
PV	photovoltaic
SPP	small power producers

Executive Summary

The Association of Southeast Asian Nations (ASEAN) Member States are at different stages of development in their solar energy potential. Each has established a national target on renewable energy as well as a target for solar photovoltaic (PV) in particular. To achieve their targets, each ASEAN nation has initiated numerous policies and supporting schemes.

Table 1. Solar PV Policies and Incentives of ASEAN Member States

ASEAN Countries	Specific Solar PV Target	FiT for Solar	Net metering Scheme	Auction for Solar PV	Tax Incentives for Solar PV	Other Types of Incentives for Solar PV
Brunei Darussalam	✔					
Cambodia					✔	✔
Indonesia	✔	✔	✔	✔	✔	
Lao PDR	✔				✔	
Malaysia	✔	✔	✔	✔	✔	
Myanmar					✔	
Philippines	✔	✔	✔		✔	
Singapore	✔		✔	✔		✔
Thailand	✔	✔	✔	✔	✔	
Viet Nam	✔	✔			✔	

Source: ASEAN Centre for Energy database (2017).

The challenges these ASEAN countries encounter as they try to meet their targets on solar energy differ from each other due to specific circumstance in their respective energy landscapes. To enhance the solar power capacity in the region, the ASEAN Member States need to overcome regulatory, technical, and financial challenges.

Table 1. ASEAN Challenges in Developing Solar PV

Regulatory	Financial	Technical
• For ASEAN nations that are in the early phase of developing their solar power market, the absence of dedicated policy or financing support (i.e. FiT, solar PPA) for solar energy is a hindrance • For ASEAN nations that have a mature solar market, the challenge is in how to transition to more efficient scheme to further reduce the cost (i.e from FiT to auction) • Inconsistent and unclear supporting policies for solar • Still lack of policy reinforcement for solar implementation as rural electrification method	• No clear investment guideline for investor to invest in solar energy • Lack of support from financial institution to finance RE projects, especially solar power	• Complicated permitting process and land acquisition issues for developing solar power plant • Land constraint for developing utility-scale solar power plant • Lack of technical expertise and experience in solar power in some ASEAN members states • No clear guidelines established for grid interconnection for solar project

PV = photovoltaics; FiT = feed-in-tariff; PPA = power project agreement.
Source: ASEAN Centre for Energy.

According to the study, at the current price level of solar PV and battery in ASEAN countries, both utility-scale solar PV + battery system; and residential solar PV + battery cannot compete with incumbent power supply options (i.e. conventional large-scale thermal power or residential electricity tariff). However, if the price of solar PV and battery decreases to the international best-price level in the future, the solar PV + battery system could compete with major conventional thermal power plants and bring benefits to residential customers as well. With ASEAN countries' domestic markets becoming more and more mature, cost reduction through economies of scale and efficiency in the supply chain can be expected.

Utility-scale Solar PV + Battery

- In the near term, with only a few utility-scale solar PV in the grid of most ASEAN countries, existing grid flexibility measures that have low costs, such as ramping capability of the gas-fired power plants, interconnection of transmission lines, and curtailment, should be preferentially used;
- Utility-scale solar PV + battery system can become a cost-effective and clean substitute for diesel as a power supply for small and isolated systems;
  - ➢ Simulation results suggest that although power generation costs of solar PV + battery at present price levels (solar PV: US$1,500/kW; battery: US$600/kWh) are still expensive (around US$0.24–US$0.30/kWh) compared with diesel, the power generation cost of solar PV + battery will be lower than that of diesel generators should there be slight cost reductions (for example, solar PV to drop to US$1,000/kW, and battery to US$300/kWh). Nowadays, prices for solar PV that are lower than US$1,000/kW and batteries lower

than US$300/kWh are already observed in global best cases (IRENA, 2017, 2018);

  - However, since batteries are not suitable for inter-seasonal or seasonal energy storage, solar PV+ battery alone is not sufficient to provide 7/24 stable power supply.

- **In the larger system,** supporting policies are needed to further bring down solar PV + battery power generation cost and make it competitive vis-à-vis conventional thermal power technologies.
  - The simulation result shows that if solar PV and battery cost could be further reduced to, for example, US$500/kW and US$100/kWh, respectively, the solar PV + battery system could compete with conventional thermal power generation technologies. According to the International Renewable Energy Agency (IRENA) and Fraunhofer Institute for Solar Energy System, the system cost of solar PV can be reduced to as low as US$630/kW until 2025 (IRENA 2016) and US$320/kW[1] until 2050 (Fraunhofer ISE, 2015). In addition, IRENA estimates that the installation cost of lithium-ion battery can be reduced to US$77–US$215/kWh until 2030 (IRENA, 2017). Given that most of the components for solar PV systems and batteries are already international circulated commodities, a cost reduction to US$500/kW for solar PV and US$100/kWh for battery is a possibility in ASEAN countries in the medium to long term.
  - Initiatives such as technical trainings for solar PV and battery project managers and installation contractors, low interest loan or loan guarantee, permits to use public land at low cost, and supports on land-use negotiations can help bring down the solar PV + battery system's generation cost.

Rooftop Solar PV + Battery

- The case study on residential solar PV in Lao PDR suggests that for typical households in a suburban area close to Vientiane, the power supply cost of a 4 kW solar PV with 5 kWh battery system can proximate the grid electricity tariff's level when the costs of solar PV and battery are reduced to US$1,000/kW and US$300/kWh, respectively.
- The economics of residential solar PV + battery is highly dependent on whether net metering is allowed or not; and on the compensation policy for the solar power fed back to the grid.
  - When the penetration of residential solar PV is still low, allowing net metering and giving certain compensation for the fed-back power can help encourage the installation of solar PV.
  - When the penetration rate goes higher, measures such as limiting the fed-back power to the grid, lowering compensation to the residential solar power sold to the grid, applying flexible electricity tariff mechanisms, and rolling out smart metering can help harmonise residential solar PV, battery, and grid operations.

[1] Converted from euro to US dollar based on exchange rate of €1 = US$1.14.

Chapter 1

Introduction

1-1 Background and Objective

The ASEAN Member States are pursuing the use of renewable energy as a step towards energy security and environmental sustainability. Amongst various renewable energies available, solar photovoltaic (PV) attracts the most attention because of its ease in installation and rapidly decreasing system cost. In some cases, solar PV can compete against conventional fossil-fired power generators. Thanks to supportive policies, its utility-scale – the so-called mega solar – and rooftop installations are expanding in the region.

However, there is a need to simultaneously invest in flexibility mechanisms – or storage technology in particularly – to absorb variable electricity output from solar PV. When a country fails to manage the fluctuation, it could result in unstable electricity supply (i.e. frequency and voltage change beyond the norm of grid regulations) and, in the worst case, could lead to a blackout. This problem regarding variable output of renewable energy and grid stability is well known amongst experts. However, in general, flexibility mechanism/technology and its application are not well understood and developed to become commercially feasible.

In this light, this study focuses on the effectiveness, necessary capacity, and cost of storage technologies so as to promote their deployment in the market and subsequently, to accelerate the penetration of renewable energy in the energy mix of ASEAN Member States.

1-2 Work Stream

This study is structured in four steps:

Step 1: Summarise the current solar PV installation and policy status in ASEAN member countries. This serves as a basis for the policy recommendations in the study.

Step 2: Provide an overview of the storage technology together with its characteristic. It covers both commercially available technology such as pumped storage hydropower generation and pilot-level technology such as compressed air storage.

Step 3: Do a simulation analysis to quantify necessary battery storage capacity against assumed solar PV output. The result is used to calculate cost of power generation of solar PV + battery system, and its cost competitiveness against conventional power generation sources is assessed.

Step 4: Deliver policy recommendations that promote a flexibility mechanism (i.e. battery storage system) in a power grid, thus encouraging renewable energy installations.

Two working group meetings were organised to discuss and share the issues.

First meeting: February 2018 in Putrajaya, Malaysia

Second meeting: April 2018 in Jakarta, Indonesia

Chapter 2

Current Status and Policy of ASEAN Member States

2-1 Overview: Development of Solar Energy in ASEAN Member States

ASEAN Member States are in different stages of development for their solar energy adoption. Each country has established a national target for renewable energy (RE), including a dedicated target for solar PV. To achieve that target, numerous policies and supporting schemes have been initiated. Such policies related to solar energy are summarised in Table 2-1.

Table 2-1. Solar Policies and Incentive in ASEAN Member States

ASEAN Countries	Specific Solar PV Target	FiT for Solar	Net metering Scheme	Auction for Solar PV	Tax Incentives for Solar PV	Other type of Incentives for Solar PV
Brunei Darussalam	✔					
Cambodia					✔	✔
Indonesia	✔	✔	✔	✔	✔	
Lao PDR	✔				✔	
Malaysia	✔	✔	✔	✔	✔	
Myanmar					✔	
Philippines	✔	✔	✔		✔	
Singapore	✔		✔	✔		✔
Thailand	✔	✔	✔	✔	✔	
Viet Nam	✔	✔			✔	

FiT = feed-in-tariff; PV = photovoltaic.

Source: ASEAN Centre for Energy database (2017).

The challenges in meeting the solar energy targets also vary from one ASEAN country to another, depending on their current energy landscape and their stage of solar development. To enhance the solar capacity in the region, these nations need to overcome three types of challenges: regulatory, technical and financial challenges (Table 2-2).

Table 2-2. ASEAN Challenges in Developing Solar PV

Regulatory	Financial	Technical
• For AMS that are in the early phase of developing their solar market, the absence of a dedicated policy or financing support (i.e. FiT, solar PPA) for solar energy is a hindrance • For AMS that have a mature solar market, the challenge is in how to transition to more efficient schemes to further reduce the cost (i.e., from FiT to auction) • Inconsistent and unclear supporting policieson solar energy • Lack of policy support for solar energy as an option in rural electrification	• No clear investment guideline on solar energy • Lacks support from financial institutions to finance renewable energy projects, especially solar power	• Complicated certification process and presence of land acquisition issues in the construction of solar power plants • Land constraint in utility-scale solar power plants • Lack of technical expertise and experience in solar power in some AMS • No clear guidelines established for grid interconnection of solar projects

AMS = ASEAN Member States; FiT = feed-in-tariff; PPA = power purchase agreement.

Source: ASEAN Centre for Energy.

Should ASEAN Member States continue to pursue solutions to these aforementioned challenges, their established targets in solar energy are achievable. Moreover, at this stage of their solar power development, most of these nations have no significant need yet to consider storage systems for tackling intermittency issues from solar power facilities. Only countries with huge solar PV injection such as Thailand have experienced the need to amplify their energy storage to smooth out the power fluctuation and stabilise the grid.[1]

However, given the growing solar development in ASEAN, the region will eventually need storage systems to absorb the fluctuating power of solar PV. Pumped storage hydropower can be one of the options for storing energy from solar PV, since the ASEAN has potential of hydropower. The list of pumped storage hydropower plants in ASEAN in 2017 to 2036 is summarised in Table 2-3.

[1] By 2017, installed capacity of solar energy in Thailand had reached around 2,400 MW.

Table 2-3. Pumped Storage Hydropower in ASEAN From 2017 to 2036

AMS	PHES	Status	Capacity (MW)	Year
The Philippines	Kalayaan Pumped Storage Power Plant	existing	349	2015
	Wawa I & II Hydro Pumped Storage Power Plants	Planning	150	Indicative power plant planning
Indonesia	Upper Cisokan Pumped Storage Plant (Cisokan, West Java).	On-going project (World bank - PLN)	520 520	2021 2022
	Sumatra	Planning	1000	2025
	Java – Bali	Planning Planning	450 450	2023 2024
	Matenggeng Pumped Storage Hydro Power Plant (West Java)	Planning	4 X 225	Indicative power plant planning
Thailand	Lam Ta Khong Pumped Storage Plant phase 1	On-going	500	
	Lam Ta Khong Pumped Storage Plant phase 12	Planning	2 x 250	2018
	Chulabhorn Hydroelectrical Power Plant	Planning	2x400	2026
	Srinagarind Hydroelectric Power Plant	Planning	3 x 267	2028
Vietnam	Bac Ai Pumped Storage Power Plant	Planning	600 600	2023 2025
Malaysia	No hydro pumped storage data			
Singapore	No hydro pumped storage data			
Brunei Darussalam	No hydro pumped storage data			
Lao PDR	No hydro pumped storage data			
Myanmar	No hydro pumped storage data			
Cambodia	No hydro pumped storage data			
Total Installed capacity			8,140	

MW = megawatt.

Source: ASEAN Centre for Energy publication, AGEP Newsletter – October 2017 Edition.

The following sections present a detailed overview of the current development of solar PV in each member state, including their installed capacity, policies on solar energy and the challenges as well as plans and potential need of each country to accommodate storage system for solar PV output.

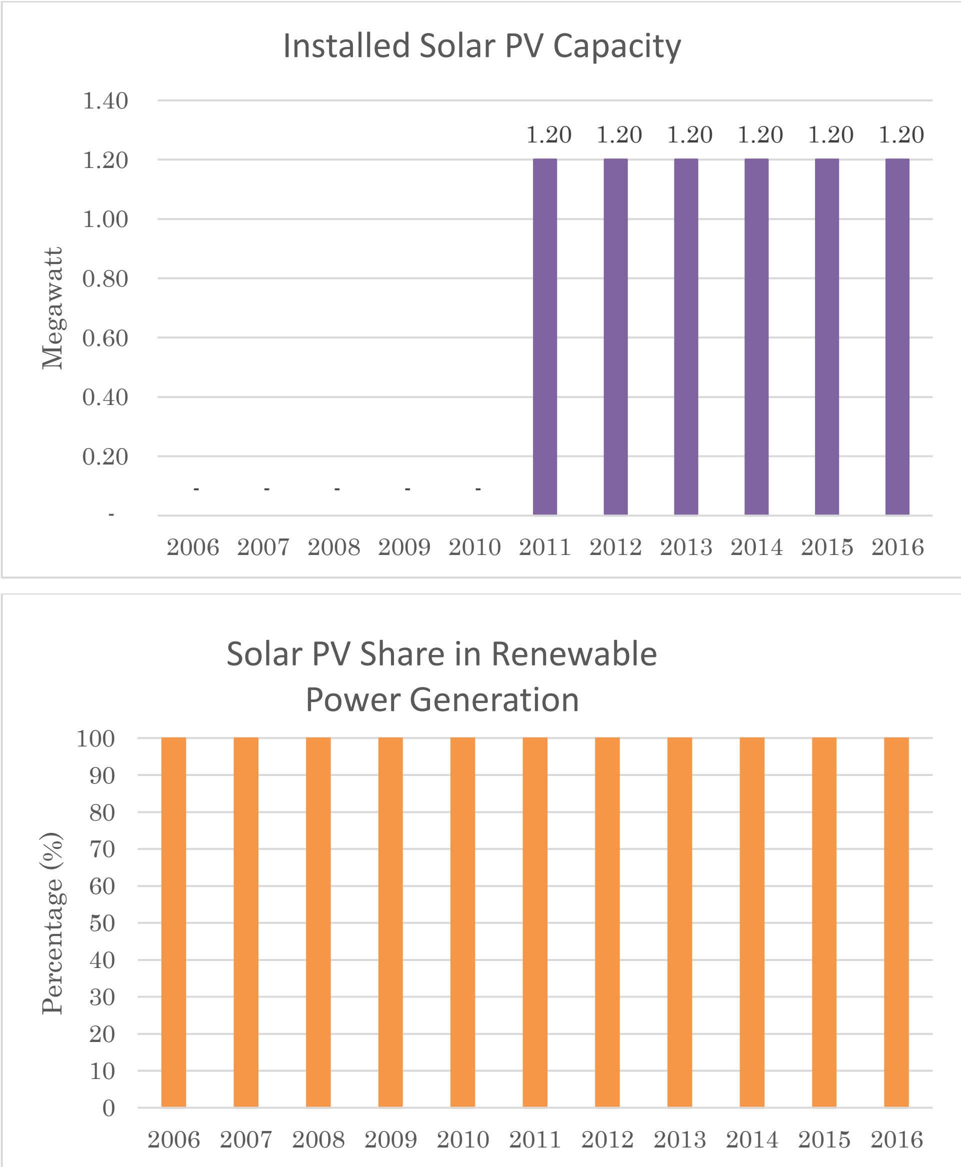
2-2 Brunei Darussalam

- Installed capacity and power generation of solar PV

Brunei Darussalam's energy sector still relies on natural gas. Its renewable energy (i.e. solar energy) accounts for around 1% of its total power generation; the total installed capacity reached

1.244 MW by 2015. Solar energy growth started since 2010 for on-grid installation, followed by off-grid installation in 2011 until 2014. However, in 2015, no solar PV installation was recorded in the country. The power generation from solar PV reached 1.12 GWh in 2015, with the biggest contribution come from the 1.2 MW Solar Park installed by Tenaga Suria Brunei.

Figure 2-1. Solar PV Capacity and Its Share in Renewable Power Generation, Brunei Darussalam



Source: ASEAN Centre for Energy database (2017).

- Promotion policy of solar PV

To achieve safe, secure, reliable and efficient supply and use of energy, the government aimed to reach 124 GWh of renewable power generation by 2017 and 954 GWh by 2035, which puts the share of RE at 10% of the total power generation mix, according to its Energy White Paper in 2014 (EDPMO, 2014). These targets are planned to be achieved through solar and waste-to-energy resources.

Currently, Brunei has not yet implemented any other supporting policies or incentives for renewable energy development, especially solar PV. It has, however, explored several supporting measures such as Voluntary Renewable Energy Certificate, net metering, and feed-in-tariff (FiT) for accelerating solar PV development. One Renewable Energy Certificate (REC) will be worth 1 MWh of renewable power generation, with the proposed fixed price at B$0.25 per kWh and B$250 per certificate REC. The RECs are open to individuals, communities, and corporate companies, but especially targeted at energy-intensive industries that generate high carbon footprints. This scheme is planned to be applied on a voluntary basis in the first five years before becoming mandatory. Current RECs originate from solar PV generation from Tenaga Suria Brunei. The government also plans to introduce fiscal incentives such as tax exemptions, rebates, subsidies as well as financial support (e.g., loans for public and private investors).

- Challenges in meeting future target

The identified challenges in meeting Brunei's target for solar PV mainly stem from the lack of clear, dedicated supporting policies and schemes. There is an observed competition from efficient gas plants, which are more appealing. A high subsidy in electricity price also becomes a factor since the solar energy price is too high to compete with a low electricity price that does not represent the true cost of generation. The price of electricity in Brunei is currently around US$0.05/kWh, while the true costs is around US$0.19–US$0.22/kWh. Geographically, Brunei is land-constrained to develop the solar panel installations. Moreover, there is a need to increase the awareness and understanding of the public and local financial institutions on RE to guarantee their support for the country's RE plans.

- Plan for absorbing fluctuating power output from solar

There is no further information on the country's strategy on how to accommodate the fluctuating solar power output, since Brunei is still in the early stage of developing its RE infrastructure and focusing on enhancing its policies first.

2-3 Cambodia

- Installed capacity and power generation of solar PV

Cambodia has developed some RE facilities in the country, mainly on hydropower and biomass, but a few are solar PV installations. The installed solar capacity in Cambodia reached 10 MW when the country's first utility-scale solar project in Bavet City (Svay Rieng Province) came online in August 2017 (Chea Vannak, 2017). Cambodia has also developed the Solar Home System programme for off-grid areas, whose systems have a capacity of 50 Wattpeak (Wp) and 5 Wp, respectively. The programme was funded by Electricite Du Cambodge and had approximately 11,240 units installation by 2016.

- Promotion policy of solar PV

Cambodia commits to increase its energy production by setting the following targets: by 2020, all villages in the country should have access to electricity; and by 2030, at least 70% of the total households in the country should have access to quality grid electricity. Consequently, the government realised that RE development has to be encouraged if it were to carry out its rural electrification plans, although no specific target for RE or solar energy has been set yet. According to its Power Development Plan 2008–2021, Cambodia aims to have 2,241 MW of renewable energy (approximately 80% of the total installed capacity) by 2020, excluding large hydro.

To date, the government has no Feed-in Tariff (FiT) scheme for solar PV. The selling tariff for off-grid renewable power generation (solar and biomass gasification) is determined by project investors and direct consumers. There was, however, a competitive bidding or auction enabled for a 10 MW solar project in 2016, which resulted in a 20-years power purchase agreement (PPA) with Electricite Du Cambodge in Bavet City.

Several fiscal and investment incentives were arranged for RE project developers, as introduced in 2003 Cambodia Investment Law. However, there were no specifics given regarding the procedure and the number of companies that can access these incentives. Those who have investments in Special Economic Zones have import duty exemption and value-added tax exemptions as privileges.

In terms of subsidy, the government allocates US$100 per system to help reduce capital investment for purchasing RE equipment. On top of that, Electricite Du Cambodge has earmarked US$6 million in 2014 as Renewable Energy Fund and for the implementation of three rural electrification development programmes: (i) Power to the Poor (P2P); (ii) Solar Home System; and (iii) Assistance to Develop Electricity Infrastructure in Rural Areas.

- Challenges in meeting future target

Cambodia does not have a structured policy yet on solar PV as it is still in its early phase of solar power development. There is also a lack of technical and financial support as well as gaps in the knowledge, experience and skills of personnel. With the first utility-scale solar farm in Bavet connected to the grid in 2017, Cambodia’s natural next steps is to scale its solar energy development in the next years. However, clearer policies and financing schemes for solar PV development have to be continuously improved.

- Plan for absorbing fluctuating power output from solar

Cambodia’s development of its solar PV system, particularly its utility-scale solar PV facility, is still in its early stage. The country is thus currently focused on growing the solar market. Looking into how to stabilise fluctuating output from solar power through storage energy systems is not yet the main priority.

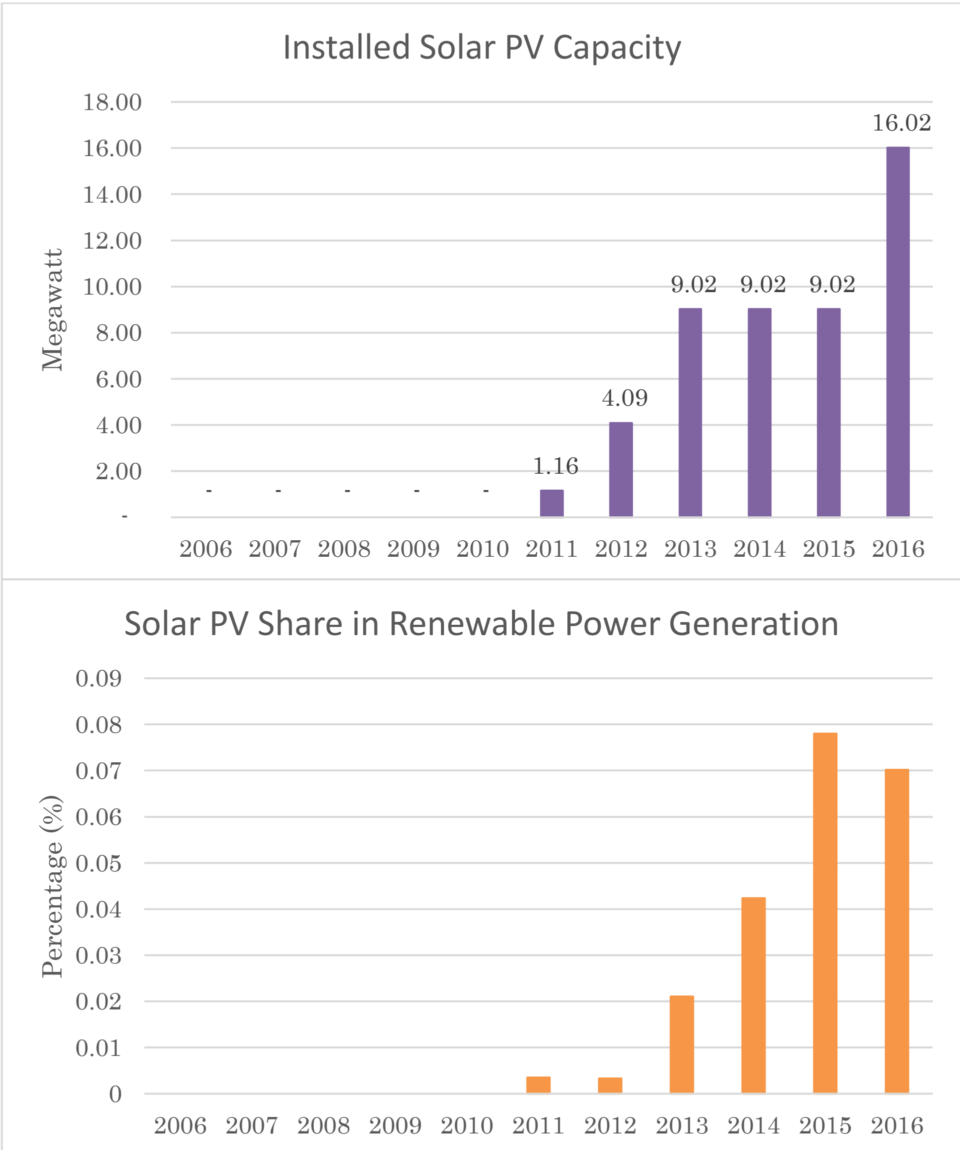
Solar batteries have been installed in solar home systems located in rural areas with the aid of several donors such as Japan International Cooperation Agency, the Korean International Cooperation Agency, the United Nations Industrial Development Organization, the Agence Francaise de Developpement, and other development organisations.

2-4 Indonesia

▪ Installed capacity and power generation of solar PV

Aided by various supporting policies, the growth in Indonesia's solar capacity started in 2010 at 0.19 MW and reached 16.02 MW by 2016. In the early days of its solar PV system, most solar panel installations were solar home systems in rural areas with a capacity of 50 Wp each.

Figure 2-2. Solar PV Capacity and Its Share in Renewable Power Generation: Indonesia



Source: ASEAN Centre for Energy database (2017).

The significant growth in solar PV in 2015 onwards started when Perusahaan Listrik Negara (PLN), a state-owned utility company, began purchasing solar PV energy in 2013. By 2016, solar power generation reached 21.09 GWh. Nonetheless, the share of solar in renewable power generation that year was less than 0.1% – miniscule compared to Indonesia's biggest RE source, which is hydropower.

- Promotion policy of solar PV

Indonesia's National Energy Policy (Government Regulation No. 79/2014) set the RE target for 2025 at 23% of Total Primary Energy Supply or about 92.2 Mtoe. This consists of 69.2 Mtoe for electricity use (~45.2 GW) and 23 Mtoe for non-electricity use. By 2050, the target share is expected to rise to 31% of the total RE. The RE target of around 45 GW installed capacity (around 33% of the total installed capacity) in 2025, is projected to come from various RE sources, including the solar energy target of 6.4 GW.

The government has also put in place various supporting policies and mechanisms for RE. For solar PV, the FiT tariff was implemented in 2013, with the rate adjusted in 2016. In 2017, the FiT mechanism was replaced by a new regulation that capped the incentives given to all RE, including solar, based on the local generation cost. Electricity generation from solar will be purchased at a maximum of 85% of the local generation cost if the price is higher than the national average generation cost. If the generation price is lower or equal to national average generation cost, the price will be determined by negotiations between PLN and the independent power producers. Furthermore, the solar plant generation cooperation between these parties will be under the *Built–Own–Operate–Transfer* scheme; that is, the power plant assets shall be transferred to PLN at the end of its lifetime.

The auction mechanism was also introduced for solar PV in 2013 by virtue of Ministry of Energy and Mine Regulation No 17/2013. Here, auctions are a procurement mechanism that sets ceiling prices for bidders. Prior to this regulation, electricity from solar PV installations was purchased by PLN through direct negotiations.

To support the use of solar PV, Indonesia has also introduced net metering policies since 2013 via Regulation 0733.K/DIR/2013. Under this regulation, PLN is obliged to credit electricity generated from a customer's account. The mechanism will offset the electricity consumed by the electricity generated from solar facilities. In case the electricity generated by solar PV is greater than the energy consumed from PLN, the customer will receive the benefit as kWh deposit to be considered or consumed in subsequent months. That is, customers do not get the benefit as monetary payment.

Since it was enacted in 2013, however, the scheme has failed to be commercially attractive because of low electricity tariffs and either lack of information or unclear guidelines about the programme. The net metering procedure also depends on the local PLN and differs by region.

There are also fiscal incentives that support RE development. The comprehensive financial support includes income tax, value-added tax, import duty, and tax borne by the government. Related regulations on RE incentives are stipulated under the Ministry of Finance Regulation No. 21/PMK.011/2010 (on tax incentive) and Regulation No. 139/PMK.011/2011 (on government financial guarantee for RE plant projects through its cooperation with independent power producers in case of PLN's failure to pay).

- Challenges in meeting future target

Challenges that inhibited solar PV development in Indonesia include the complicated procedures on permits for ground-mounted solar projects. This can increase the project development cost, which further diminishes a project's attractiveness. Another relates to the unclear policies on net metering systems and lack of attractive tariffs for utility-scale solar farms.

In a net metering system, the policy did not provide compensation beyond (future) own consumption. This policy is also unattractive because of the minimum payment charged each month for grid connection.

Other challenges that inhibit the development of solar power plants in Indonesia are (PricewaterhouseCoopers, 2017; ASEAN Center for Energy Database, 2018):

a) Lack of appropriate regulatory support;
b) Weak multi-stakeholder (e.g., government, investors) coordination on permit issuance: e.g. lengthy process on permits for land acquisition and grid connectivity.
c) Limited infrastructure support such as ports and roads, particularly in rural and remote areas;

d) Lack of technical expertise and experience in Solar PV technology, including risk mitigation;
e) Additional restriction and requirement regarding locally produced/manufactured content, as stipulated by government policies.

- Plan for absorbing fluctuating power output from solar

There is no information on how the government of Indonesia plans to mitigate the fluctuating power output from solar power generation. However, small-scale solar PV batteries are increasingly being used and deployed as mini/micro grids to electrify rural areas in Indonesia. The system combining solar PV and storage is one of the suitable options in dealing with electrification of rural and remote places via distributed/ mini-grids.

Indonesia has started the construction of the nation's first pumped storage hydropower plant in Upper Cisokan, West Java, which has a total capacity of 1,040 MW (RambuEnergy, 2017). The funding from the World Bank at the amount of US$640 million has been disbursed since 2011 (The World Bank, 2017). Construction of the plant will begin in February 2017 and is expected to be completed within 50 months.

The Upper Cisokan Pumped Storage power project is aimed to significantly increase the peaking capacity of the power generation system in Java, Bali in a more sustainable way. Although this can be seen as the country's attempt to explore pumped storage hydropower as an alternative for energy storage, the project is not planned to be a solution to the intermittency issue from solar PV or other renewables.

2-5 Lao PDR

- Installed capacity and power generation of solar PV

Lao PDR's solar PV installed capacity is small when compared to the resource potential. Solar PV in Lao PDR is still confined to rural electrification and off-grid installations. There had been no official announcement on the solar PV installed capacity in the country until 2017 for on-grid or off-grid application. However, in 2017, Lao PDR's first utility-scale solar panel installation of 10 MW was brought online. In the first phase, the project is expected to generate 32–50 MW in total from 2017 to 2018. By 2020, the amount generated will rise to 100 MW (Xinhua News, 2017).

- Promotion policy of solar PV

Per Lao PDR's Renewable Energy Development Plan, the government aims to increase RE's share of the final energy consumption by 30% in 2025 (excluding that from large hydropower plants). The detailed target for solar PV is to reach 36 MW in 2016–2020 and 91 MW in 2021–2025 for electricity; and 22 ktoe in 2016–2020 and 109 ktoe in 2021–2025 for heat.

Lao PDR has not issued supporting policies and schemes for its RE other than tax incentives for investment promotion. The country is still in the process of preparing FiT tariffs for different types of RE. Thus, the FiT for grid-connected RE, especially for solar, is not yet in place. The selling tariff of the electricity generated from RE is currently based on negotiations between producers and the power utility.

Tax incentives for RE – duty-free import of production machinery, equipment and raw materials, and profit tax exemption and reduction at rates that are based on the investment zones – are stipulated under the Investment Promotion Law.

- Challenges in meeting future target

One of the technical challenges in the development of solar PV in Lao PDR is the country's lack of implementation standards for solar projects; hence, the country is still in its learning stage. Although a series of RE policies have been issued, most are for hydropower projects. Lao PDR has no policies and regulatory framework for solar PV development. Neither is there specific support for solar energy such as FiTs, and no access to loans that can finance solar projects.

- Plan for absorbing fluctuating power output from solar

The solar PV market in Lao consists mostly of solar home systems for rural electrification. The country is still in its early phase in terms of utility-scale solar development. Hence, it does not yet have concerns on wide-area intermittency from solar PV.

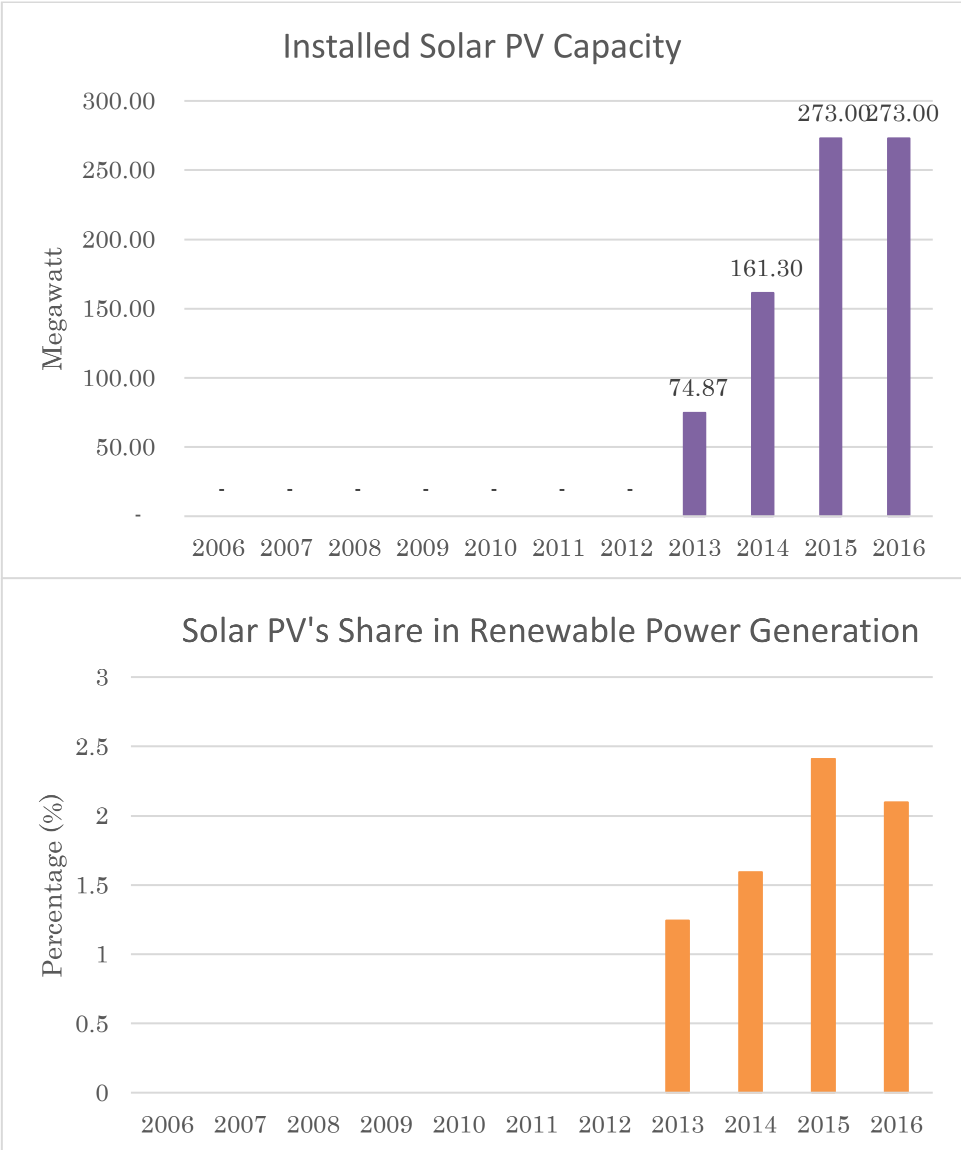
However, given the abundant resources for hydropower in Lao PDR, pump storage hydropower is a potential storage option that may be able to mitigate solar energy intermittency in the future.

2-6 Malaysia

- Installed capacity and power generation of solar PV

Prior to the introduction of the FiT mechanism in December 2011, the size of Malaysia's solar PV projects was deemed small. After the implementation of FiT, installed solar PV capacity began to rise from around 74.87 MW in 2013 to 273 MW in 2015.

Figure 2-3. Solar PV Capacity and Its Share in Renewable Power Generation: Malaysia



Note: 2016 data is a projection.

Source: ASEAN Centre for Energy database (2017).

This rapid increase is due to several support mechanisms, especially the FiT programme with its attractive rate. The power generation was recorded at 621.78 GWh by 2016, with solar PV accounting for around 2% of the total renewable power generated.

- Promotion policy of solar PV

Based on the National Renewable Energy Policy and Action Plan 2010, Malaysia has set targets for RE from 2015 to 2030. One of the targets is to achieve installed RE capacity (from various RE sources such as biomass, biogas, mini-hydro, solar PV, and solid waste) of 2,080 MW by 2020 and 4000 MW by 2030. For solar PV, the country targets 190 MW by 2020 and 1,370 MW by 2030.

Ever since the country committed to bring RE into its energy supply mix in 1999, a number of policies and supporting mechanisms have been put in place. Feed-in-tariff in the country is only applicable to RE technologies; rates for solar PV, were adjusted several times – in 2013, 2014, and 2015 – in response to the drop in the RE technology's cost. Since 2017, the quota for new solar PV project is no longer available due to limited RE Funds, which was used to pay for the FiT premium rates for solar PV.

However, the quota for other energy sources will still be in place based on the availability of the RE Fund. Since 2016, the country has moved from full amount purchase to the self-consumption scheme, including net metering (for the distributed PV system) and auctions (for the utility-scale PV system). This means, that there has been no FiT incentive given for new solar plant since 2016.

As of January 2018, the FiT rates for different RE in Malaysia are as follows (Sustainable Energy Development Authority, 2018):

Table 2-4. Solar FiT in Malaysia, 2018

Solar PV (Community)	FiT Rates (US cents/kWh)
a) Basic FiT rates having installed capacity of:	
(i) Up to and including 4 kW	17.09
(ii) Above 4 kW and up to and including 24 kW	16.67
(iii) Above 24 kW and up to and including 72 kW	11.34
b) Bonus FiT rates having the following criteria (one or more):	
(i) Use as installation in buildings or building structures	+3.21
(ii) Use as building materials	+2.17
(iii) Use of locally manufactured or assembled solar PV modules	+1.28
(iv) Use of locally manufactured or assembled solar inverters	+1.28
Solar PV (Individual)	
a) Basic FiT rates having installed capacity of:	
(i) Up to and including 4 kW	17.09
(ii) Above 4 kW and up to and including 12 kW	16.67
b) Bonus FiT rates having the following criteria (one or more):	
(i) Use as installation in buildings or building structures	+3.21
(ii) Use as building materials	+2.17
(iii) Use of locally manufactured or assembled solar PV modules	+1.28
(iv) Use of locally manufactured or assembled solar inverters	+1.28
Solar PV (Non-Individual)	
a) Basic FiT rates having installed capacity of:	
(i) Up to and including 4 kW	17.09
(ii) Above 4 kW and up to and including 24 kW	16.67
(iii) Above 24 kW and up to and including 72 kW	11.34
(iv) Above 72 kW and up to and including 1 MW	10.96
b) Bonus FiT rates having the following criteria (one or more):	
(i) Use as installation in buildings or building structures	+3.21
(ii) Use as building materials	+2.17
(iii) Use of locally manufactured or assembled solar PV modules	+1.28
(iv) Use of locally manufactured or assembled solar inverters	+1.28

FiT = feed-in-tariff; PV = photovoltaic.

Note: * Exchange rate: RM3.91/US$(6 March 2018).

Source: Sustainable Energy Development Authority website (2018).

The Energy Commission is the regulator for the net metering scheme, while the Sustainable Energy Development Authority–Malaysia is the implementing agency. The electricity generated by a customer will be purchased by utilities at below retail rates, which are determined based on the utility's unit cost. This utility cost reflects the average cost of generating and supplying per kWh of electricity from other sources (excluding RE) through the supply line until the point of interconnection with RE installations. The net metering scheme will be introduced with a total capacity of 500 MW from 2016 and 2020 (with a 100 MW capacity limit each year, where 90% is allocated to Peninsular Malaysia and 10% to Sabah).

Meanwhile, the country enacted its first solar PV auction scheme for large-scale solar plants in 2016. The first and second auctions were completed in 2016 and 2017, respectively. Projects with a total target capacity of 1,250 MW have been awarded to large-scale solar plants with capacities of 1 MW to 50 MW per project. Two auctions were completed: The first auction awarded contracts with a total quota of 409 MW in 2016. A second auction, made in 2017, was for a total capacity of 557 MW.

The remaining 270 MW project was given via direct award. All these projects are to be completed by 2020.

Other incentives for solar PV were in the form of tax incentives. According to the Malaysian Investment Development Authority, qualified RE projects are eligible to apply for an investment tax allowance of 100% of qualifying capital expenditures and income tax exemption. For solar PV, a sales tax exemption of 10% is granted for PV modules that are manufactured in Malaysia.

Malaysia has also been provided a financing scheme for all renewable technologies available under its Green Technology Financing Scheme (GTFS) since 2010. The financing scheme is managed by the Malaysia Green Technology Corporation and Credit Guarantee Corporation Malaysia Berhad and open to companies that are predominantly Malaysian-owned. That is, if the company is an energy producer, then the minimum percentage of Malaysian shareholding should be 51% to qualify. If the company is an energy user, the minimum shareholding must be at least 70%.

- Challenges in meeting future target

Since Malaysia's solar energy sector is one of the most mature in the ASEAN, with the country already moving towards self-consumption and net metering schemes, one of its challenges is to determine the capacity and suitable tariff (or the displaced cost) of rooftop solar PV as such is not based on netting of energy as per the usual practice. The excess energy is paid at the displaced costs, which are RM 0.31/kWh for low voltage and RM 0.238/kWh for medium voltage connections.

- Plan for absorbing fluctuating power output from solar

Malaysia has not yet experienced any issues with the intermittency behaviour of its solar power facilities. It is still in the process of determining the level of penetration that would justify the need for energy storage systems. At present, the share of RE in the total generation mix is less than 2% (excluding large hydropower facilities).

2-7 Myanmar

- Installed capacity and power generation of solar PV

Myanmar's RE sector is still in its early stage. Currently, its RE generation is limited to hydropower projects and small solar PV installations from solar home systems. Its solar home systems' installed capacity until 2014 is estimated at 14.55 MW.

- Promotion policy of solar PV

Myanmar is still in the process of crafting its policies and framework for RE. In the second draft of its RE policy, its RE installation target is set at 26.8% – or 3,995 MW of the total capacity of 14.9 GW – by 2030. No other information was found on the composition of such target by RE source.

Currently, Myanmar has no framework or supporting schemes for the development of RE other than tax incentives. Through the Foreign Investment Law, such incentives are in the form of income tax exemption for up to five years, depreciation, and additional tax deductions. The country also offers incentives to investors and developers located in special economic zones.

- Challenges in meeting future target

Myanmar is currently finding solutions to its electricity shortages and is focused on increasing the electrification ratio across the region. Financing the developing of its solar PV sector is another of its most challenging issues because of limited financing support. On the technical end, there is a lack of guidelines and clear policies on solar PV development. For instance, there is no incentive given to solar PV participants.

- Plan for absorbing fluctuating power output from solar

Because solar PV in Myanmar is still limited to rural electrification and solar home systems, there is no urgency to implement storage systems meant to mitigate intermittency issues on the grid. Instead, small-scale storage meant for solar home systems is needed to improve services in rural areas.

2-8 Philippines

- Installed capacity and power generation of solar PV

Solar energy development in the Philippine started in 2014 with the enactment of the Renewable Energy Act (RA 9513). The Act intends to accelerate the exploration and development of RE resources by achieving self-reliance, adopting clean energy and promoting socio-economic development in rural areas. In 2016, solar PV installation jumped from 165 MW in 2015 to 736 MW in 2016 surpassing the government's target for solar PV installation.

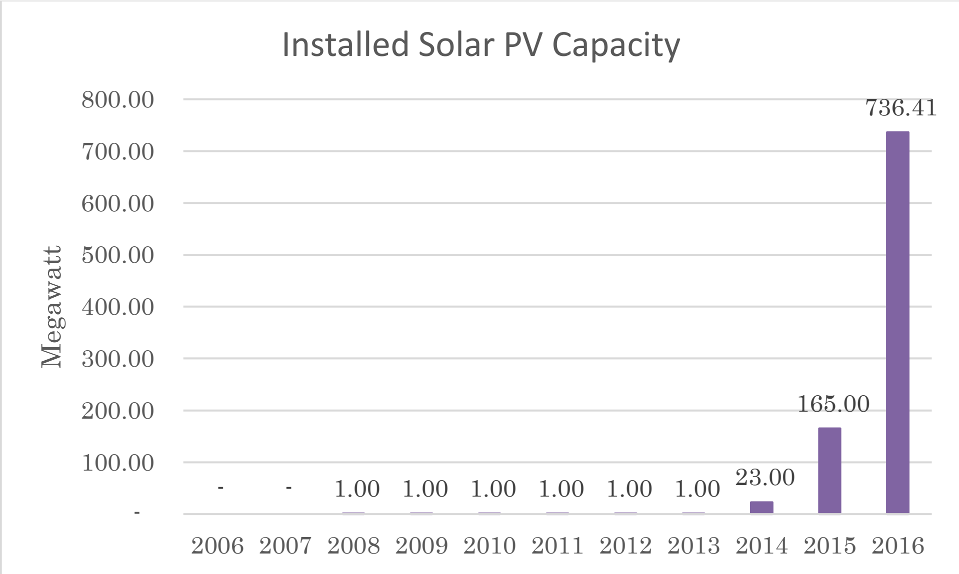
The increased capacity of solar energy facilities was also driven by the energy crisis in 2015. Most of the targets for RE (solar, wind, and biomass) in the Philippine National Renewable Energy Plan 2010–2030 have been achieved. Hence, the Department of Energy is now in the process of reviewing and setting a new target for National Renewable Energy Plan 2017–2040.

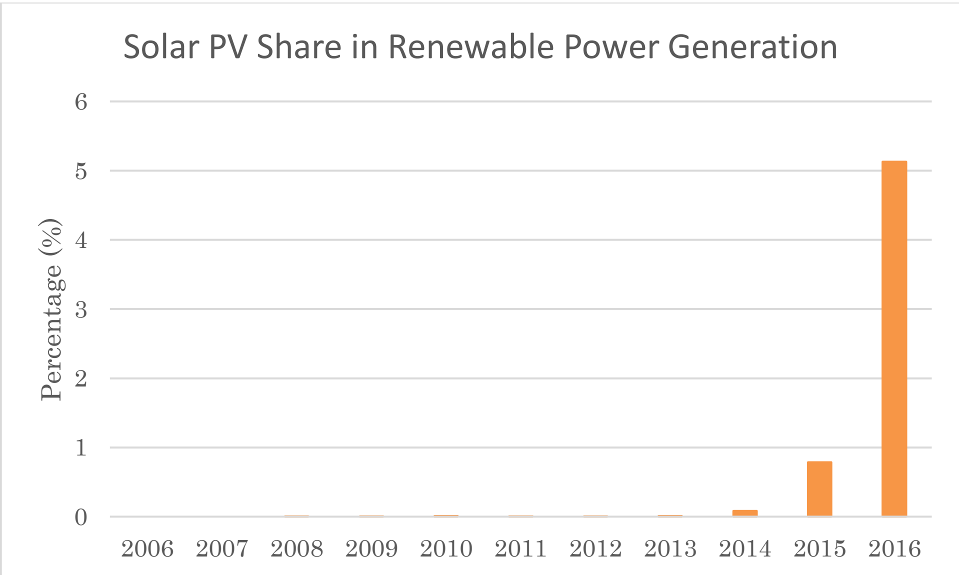
Power generated from solar PV in 2016 was 1,089 GWh, accounting for 5% of the total RE generation in the country.

- Promotion policy of solar PV

Under the Renewable Energy Act 9513 and the National Renewable Energy Plans and Programs 2011–2030, the Philippines identified strategies and targets to accelerate the exploration and development of RE resources. The regulations revised targets for installed RE capacity from its 2010 baseline level of 5,438 MW to 15,304.30 MW in 2030. For solar PV, the targets were (i) to achieve grid parity in 2020; and (ii) to hit 284 MW in installed solar PV capacity by 2030. However, due to the progressive efforts taken in developing solar PV, the target was already hit in 2016.

Figure 2-4. Solar PV Capacity and Its Share in Renewable Power Generation: Philippines





Source: ASEAN Centre for Energy database (2017).

Multiple policies favouring renewable energy were pursued since 2008. In 2017, the President's Executive Order No. 30 created the Energy Investment Coordinating Council, which was tasked to streamline the regulatory procedures affecting energy projects. Through the executive order, the government also created Energy Projects of National Significance (EPNSs).

The EPNSs are major energy projects for power generation, transmission, and/or ancillary services, including those required to maintain grid stability and security. These are identified and endorsed by Department of Energy for projects that possess the specific attributes mentioned in the executive order.

The executive order also created and mandated the Energy Investment Coordinating Council to assist in the regulatory process related to energy investments, mainly on EPNS. The council is directed to act upon applications for permits, including EPNS, within 30 days from the date of submission. This is expected to hasten the process of power project implementation in the country.

The Philippines has also provided several financing mechanisms and a framework for the development of solar PV. In 2012, it approved the FiT scheme. In 2015, it revised the FiT rates for solar PV generation. These rates include degressive rates across the years. The FiT rate for solar power is a fixed rate of US$0.1671/ kWh (at the exchange rate of ₱52.01/US$ as of 6 March 2018*).*

The country has also approved the net-billing framework in 2008 and implemented it in 2013. The excess electricity injected into the grid is purchased at 50% of the retail rate. The programme was well received, gathering 932 participants by May 2016, and continuously growing with a 7% month-to-month increase in installed capacity in 2016, influenced by the declining PV system cost and high electricity cost.

Under Republic Act 9513, the country gave RE projects several tax incentives such as income tax exemptions and reduction; duty exemption on RE machinery, equipment and materials; special realty tax rate on equipment and machinery; value-added tax exemption; accelerated depreciation; loss carry-over; tax exemption of carbon credit; and tax credit on domestic capital equipment and services. Moreover, RE projects that are supported or endorsed by the Department of Energy are given financial support by government financial institutions such as the Development Bank of the Philippines and Land Bank of the Philippines.

In addition, the Philippines is in the process of formulating Renewable Portfolio Standards and preparing the market for Renewable Energy Certification. In 2016, the final draft of the Renewable Portfolio Standards was released by the Department of Energy for approval.

- Challenges in meeting future target

The challenge for the Philippine government lies in how it will balance energy security with commercial project development. The surge in applications for solar PV projects due to the attractive FiT rate led the government to halt the programme in 2017. The country is now evaluating its FiT scheme vis-à-vis what it had attained for solar PV development and is, in fact, moving towards the auction scheme in the future.

Also, the country has not yet implemented its rural electrification project using solar PV since there is demand still for cheaper and more reliable off-grid electricity. Off-grid generation is still dominated by conventional sources, particularly diesel. The country is on its way toward formulating RE targets in its rural electrification plan.

- Plan for absorbing fluctuating power output from solar

There are not much details on how the Philippines plans to tackle the intermittency issues in solar PV generation, despite the remarkable growth of the solar energy sector. However, the country has explored the use of pumped storage hydropower plants since 1982 in Kalayaan as the energy storage option (CBK Power, 2018). Kalayaan has facilities, built in Laguna Lake, consists of Kalayaan I (168 MW) and Kalayaan II (174.3 MW), which serve as large peaking facility for the Luzon grid and more importantly, in balancing frequency. The Philippines has the potential to explore pumped storage hydropower plants as storage in its bid to solve the intermittency issues of utility-scale solar PV generation, since the hydropower potential is still abundant.

The country is also on its way towards establishing the biggest solar-battery microgrid in Paluan, Mindoro, which was started in the third quarter of 2017 with Solar Philippines as the developer. The solar-battery microgrid in Mindoro will operate with a capacity of 4 MW (Bussiness World, 2017).

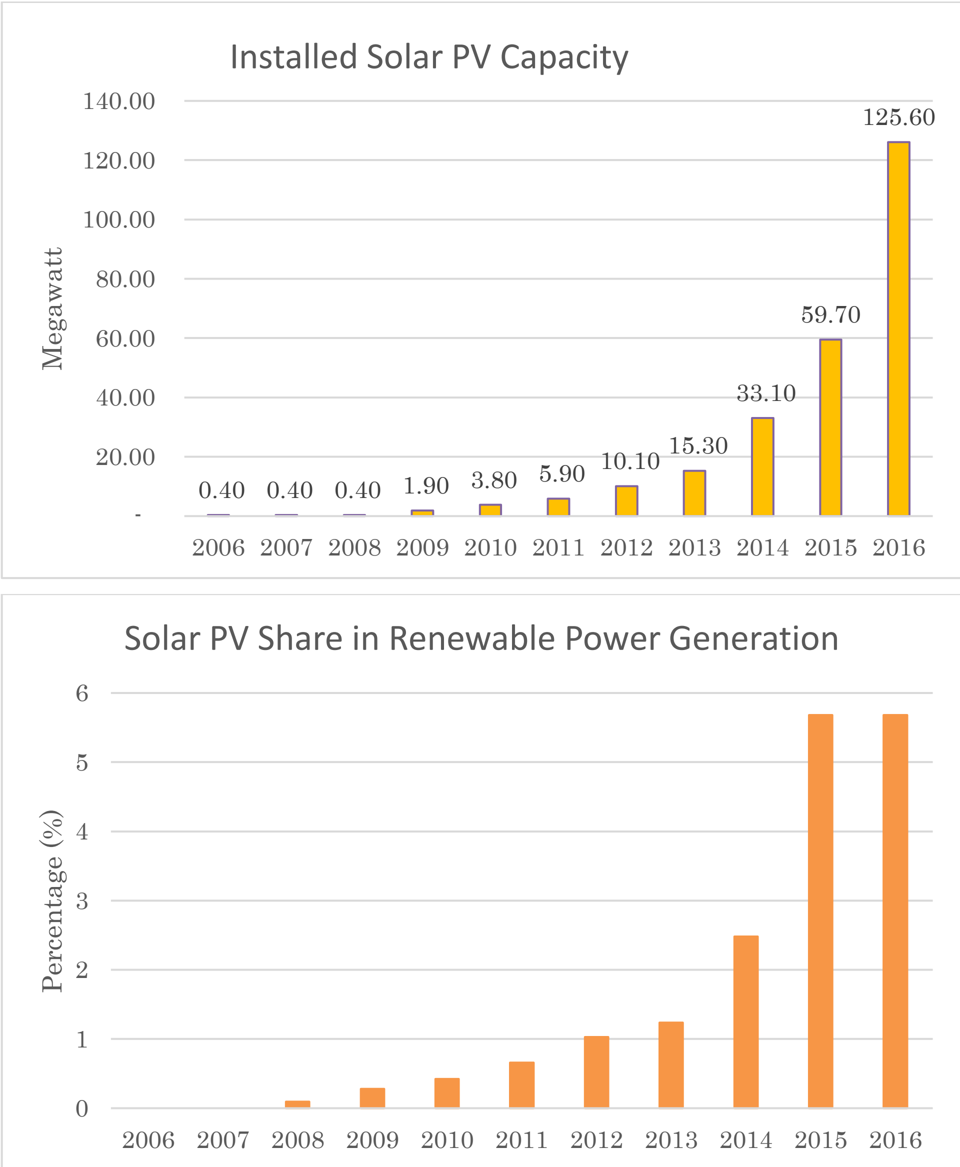
2-9 Singapore

- Installed capacity and power generation of solar PV

Due to its geographical constraints, the most feasible RE type for Singapore would be solar PV. From 2008 until the end of 2016, the country has seen a significant rise (from 30 to 1,826) in solar panel installations. For the same period, the total installed capacity grew from 0.4 MW to

125.6 MW. Although most of the solar panel installations are from residential consumers, there also has been a notable growth in installations from non-residential sectors since 2012. The trend is predicted to accelerate over the next few years due to the fall in prices and rapid improvement in the technology. Power generation from solar PV until 2016 is at 123.14 GWh, with solar PV accounting for 5.5% of the total RE generated.

Figure 2-5. Solar PV Capacity and Its Share in Renewable Power Generation: Singapore



Source: ASEAN Centre for Energy database, 2017.

- Promotion policy of solar PV

Because the RE options are limited by its geography, Singapore is focusing on tapping the potential of solar PV. Amongst its commitments as documented in the Singapore Sustainability Blueprint is to meet its RE consumption target of 350 MWp for solar power by 2020.

To support the adoption of solar PV systems in Singapore, the Energy Market Authority has improved the regulatory framework for intermittent generation sources (IGS) – which includes RE – by streamlining the process and regulating the payment in the delivery of excess electricity to the grid. The IGS framework adopts the net metering principle for embedded IGS. The IGS producers are not offered a FiT scheme; instead, market payments and charges are applied.

The IGS framework is applicable to contestable customers with less than 1 MWac embedded IGS. Meanwhile, there is no further information regarding the payment and charges for those with capacity of 1 MWac or more or for stand-alone IGS that sell electricity in the market. This study notes, however, that starting February 2016, solar retailers could directly sell electricity from solar PV systems to the grid at the market price, which then delivers power to interested customers.

To support the growth of RE, the Singapore Productivity and Innovation Credit provides tax deduction/allowance and/or cash payout to encourage research and development in green innovation. The allowance includes a 400% tax deduction on the first S$400,000 of qualifying Research and Development expenditure for each year of assessment, and 150% in excess of S$400,000. A non-taxable cash payout equivalent to 60% of up to S$100,000 of the qualifying expenditure has been made available to businesses since 2013. The government also extensively supports RE development by allocating funds and creating programmes to support research and development such as Clean Energy Research and Test-Bedding Programme, Energy Innovation Research Programme, Clean Energy Scholarship Programme, Market Development Fund, Energy Research Development Fund, and Energy Training Fund.

A government-led solar rooftop auction programme called 'SolarNova' was initiated in 2015 by Singapore Economic Development Board to spur solar PV development in Singapore. This programme targeted a 40 MW-capacity rooftop installation on 839 government buildings across the country. The installation was expected to be complete by the end of 2017. A second auction was announced in late 2016, which aimed to install 40 MW of solar PV panels across nine government agencies. This project is expected to be completed in the first quarter of 2019.

The government also foresees the growth of 'prosumers' – electricity customers who are able to sell the electricity back to the grid – and has taken proactive steps, including streamlining payment procedures for prosumers, establishing a central intermediary who handles administrative necessities in the solar market, and enhancing market and regulatory frameworks by providing innovative business models such as solar leasing.

- Challenges in meeting future target

Because of the limited land area, Singapore is confined to rooftop solar panel installations and cannot implement wide-scale solar PV projects. Hence, the country may explore other options such as floating solar PV.

Singapore is also developing solutions in response to the intermittent nature of solar PV. A back-up system is required to recover the generation and maintain the system's stability when weather conditions change. Reserves mostly come from conventional power sources in Singapore.

- Plan for absorbing fluctuating power output from solar

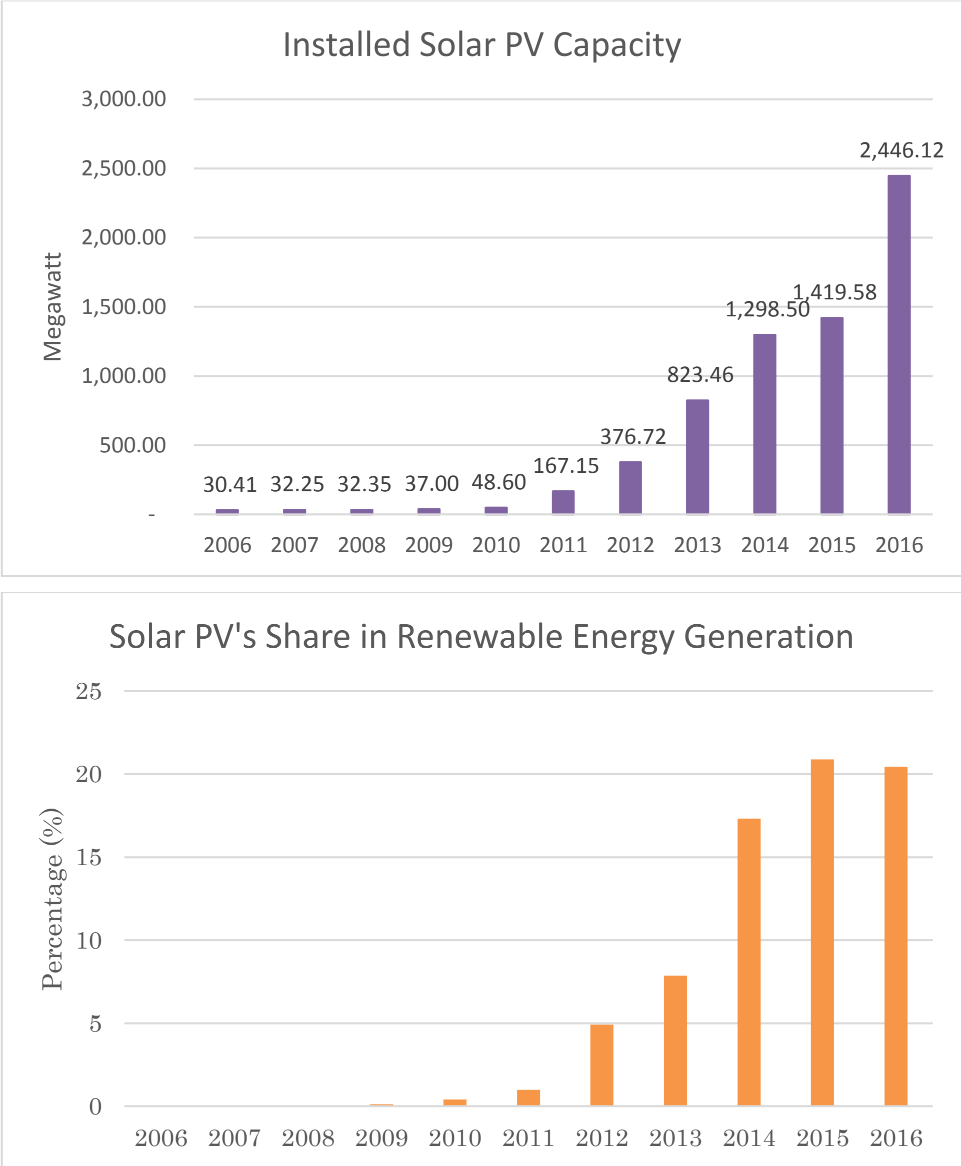
There is no need yet to incorporate storage systems into the grid given that utility-scale solar power development in Singapore is limited by its space. However, since solar PV is mostly deployed as solar PV rooftop installations, the country must prepare for the time when it would need to install storage system to mitigate future intermittency issues.

2-10 Thailand

- Installed capacity and power generation of solar PV

Thailand has several RE facilities on biomass, hydropower, waste-to-energy, and solar power. Its number of solar PV installations has grown since the Adder scheme was implemented in 2007. Much higher growth was seen since 2011, after various supporting policies were enacted. By 2016, solar PV capacity reached 2,446.12 MW while power generation from solar PV was 3,430 GW. During the period, the share of solar PV in the renewable power generation mix was about 20%.

Figure 2-6. Solar PV Capacity and Its Share In Renewable Power Generation: Thailand



Source: ASEAN Centre for Energy database (2017).

- Promotion policy of solar PV

According to the Alternative Energy Development Plan, Thailand aspires to have RE account for 30% of the total energy consumption; 15% to 20% of electricity generation; 30% to 35% of the total heat generation; and 20% to 25% of biofuel production by 2036. This target of 30% RE share is further broken down by source type such as biogas, biofuel, hydropower, and wind power. In the power sector, the respective targets for installed capacity of solar and heat application by 2036 are 6,000 MW and 1,200 ktoe, respectively.

To support the development of RE (especially solar PV), Thailand was the first country in ASEAN to introduced the precursor of the FiT scheme in 2007: the Adder scheme. During that time, RE generation could be purchased by paying a fixed amount on top of the wholesale electricity tariff. For solar energy, under the Adder scheme, the amount purchases from the electricity producer are for the period of 10 years. In 2014–2015 the Adder scheme was replaced by a comprehensive FiT policy for hydro, wind, solar, municipal solid waste, biomass, and biogas. Thailand also provided a premium FiT for projects with special conditions, such as those located in four southern provinces of Thailand. Under this new FiT scheme, the PPA duration is 20 years.

Table 2-5. Solar Feed-in-Tariff (FiT) in Thailand 2018

RE Technology	FiT (US cent/kWh)	FiT Premium–Southern provinces (US cent/kWh)
Rooftop (0 – 10 kWp)	21.81	1.59
Rooftop (>10 – 250 kWp)	20.38	1.59
Rooftop (>250–1000 kWp)	19.13	1.59
Ground mounted (<= 90 MWp)	18.02	1.59
Ground mounted (government site and agriculture cooperative <= 5 MW)	18.02	1.59
PV ground mounted (agriculture cooperative <= 5 MW for 2016–2017)	13.12	1.59

RE = renewable energy.

Note: Exchange rate 31.61 THB /US$ (6 March 2018).

Source: DEDE Thailand (2017).

Net metering in solar PV, first introduced in Thailand in 2002, gives customers 80% of the retail rate for the electricity that they inject into the grid. However, this scheme was not well received and did not significantly drive distributed solar PV investment due to the high upfront cost of solar PV systems before 2008. Later, in 2013, the government introduced a national rooftop FiT programme with a limited quota of 200 MW. By the end of the programme in 2015, the large-scale distributed solar PV system (i.e. large commercial and industrial rooftop installations) was mature for self-consumption.

In 2017, the Energy Regulatory Commission introduced the SPP Hybrid Firm scheme, which is a FiT-scheme PPA bidding process for small power producers (SPPs). The scheme aims to enable multi-source RE projects as well as to move from a non-firm PPA to a firm PPA.

Under this hybrid PPA, a combined power generating capacity of 300 MW will be allocated nationally, with the greatest allocation going to southern, northern, and northeastern Thailand. The Energy Regulatory Commission will review applications from SPPs for the sale of capacities between 10 MW and 50 MW through a competitive bidding process.

Before this regulation was enacted, RE PPAs were 'non-firm' and accommodated the delivery of electricity below the installed capacity of a power plant. Hence, the SPP Hybrid is intended to reduce the variations in intermittent RE and will require a continuous baseline-level production not seen in previous stand-alone solar or wind power farms.

The FiT for SPP Hybrid firm is set at ฿3.66/kWh or about US$0.1156/kWh (exchange rate of ฿31.61/US$ on 6 March 2018). Table 2.6 presents the details of the FiT for SPP Hybrid Firm scheme.

Table 2-6. FiT for SPP Hybrid Firm in Thailand

Installed capacity (MW)	FiT (US cent/kWh)			Period (years)
	Fixed FiT	Variable FiT	Total FiT	
Installed capacity >10–50 MW	5.76	5.89	11.65	20

FiT = feed-in-tariff; SPP = small power producers.

Note: Exchange rate ฿31.61/US$ (6 March 2018).

Source: DEDE Thailand (2017).

The SPP Hybrid scheme requires the RE generator to deliver between 98% to 102% of the PPA capacity during the 'peak' periods (between 9:00 a.m. and 10:00 p.m., Mondays to Fridays) and limits power output outside the peak period to 66.3% of the PPA capacity. In this new scheme, applicants are required to specify the types of RE which will be used as a power plant, but there are no minimum types of RE to be used, and nor restrictions of RE to be applied. In other words, all combination of RE types and integration with energy storage are allowed (Williams, 2017).

The Energy Regulatory Commission also launched the Self-consumption PV Pilot Programme in August 2016. During the initial stage, there was no required compensation for electricity to be injected into the grid. However, in the next phase of the programme, which was expected to start in 2017, there was a plan to set a buyback rate for the excess electricity, after monitoring and evaluation was to be completed.

Thailand's Board of Investment promulgated multiple tax incentives for RE developers. Several investment promotions were introduced for sustainable development industry activities such as income tax holiday, exemption from import duties for RE equipment, and corporate income tax reduction.

A number of programmes also provided financing support for the promotion of RE. Under Industry Act 2007, the Energy Regulatory Commission established the Power Development Plan, which included RE promotion. Additionally, the Department of Alternative Energy Development and Efficiency set up the Energy Service Company Revolving Fund (which was created under the Energy Conservation Promotion Fund) in 2008, to invest, along with private operators, in RE and energy efficiency initiatives. Investment services covered by the Energy Service Company Revolving Fund includes equity investment, equipment leasing with low interest, venture capital, greenhouse gas reduction project facility, and credit guarantee facility.

Finally, the government also provides capital subsidies for RE power projects that are operated and owned by government agencies.

- Challenges in meeting future target

Thailand is ahead of the rest in the ASEAN in terms of solar energy development. The market for solar energy has been nurtured by various incentives, starting with the introduction of the Adder scheme in 2007, which was replaced by the FiT scheme in 2014. Thailand's comprehensive FiT scheme for solar energy consists of a fixed FiT and a premium rate for specific regions. On the other hand, the SPP Hybrid Firm, which was introduced to encourage integration of storage systems in RE, was not well received by project developers, since the FiT offered was deemed too low, given the size of the required investment in the storage battery appropriate for the hybrid power plant.

- Plan for absorbing fluctuating power output from solar

According to state enterprise Electricity Generating Authority Thailand, the country is currently using battery banks to mitigate the fluctuating power output from renewables, especially solar power. For energy storage, the pumped storage hydropower is an option. At present, the battery bank's capacity is 10 MW while the pump storage hydropower capacity is around 200 MW. The country is expected to continue to top up this capacity, considering the growing renewable energy generated (EGAT, 2018).

2-11 Viet Nam

▪ Installed capacity and power generation of solar PV

Until 2015, there was no utility-scale solar PV installed in Viet Nam. Solar panel installation in the country was limited to small-scale application for off-grid electricity supply, specifically for building and households. However, ever since FiT was introduced in 2017, construction projects on utility-scale solar PV plants increased in number.

▪ Promotion policy of solar PV

The RE target in Viet Nam, as stipulated in the current Power Development Plan, consists of 11% RE share of 60 GW installed capacity in 2020; 13% RE of 96 GW in 2025; and 21% RE of 130 GW in 2030. Renewable energy consists of 2.1% wind, 15.5% hydro, 2.1% biomass, and 3.3% solar out of the total installed capacity in Vietnam. In particular, solar PV installation is expected to be 850 MW in 2020, 4000 MW in 2025, and 12000 MW in 2030.

To hit the targets, the government introduced the FiT scheme for solar farms and rooftop generation (net metering) in June 2017, as set out by the Prime Minister's Decision No. 11/2017/QD-TTg. The FiT for solar PV is D2,086/kWh – or equivalent to US$0.0935/kWh (exclusive of value-added tax) – and intended for any projects that can achieve a commercial operation date before the end of June 2019.

Following the issuance of Decision No. 11 on solar power, the Ministry of Industry and Trade of Viet Nam also released the first draft of a circular that provides detailed guidelines on the development of solar power projects in Viet Nam. The circular includes the draft of the solar PPA template as well as details of national and provincial solar power development plans. Under the draft solar PPA, Vietnam Electricity Corporation shall purchase the generation facility in a 20-year contract.

Under Decision No. 11, the government provides similar investment incentives as those for wind power projects. It has duty exemption for imports of solar components, corporate income tax deductions, and land use incentives. The government also offers state investment credit to eligible solar power projects under Decree No. 32/2017/-ND-CP dated 31 March 2017. According to this decree, investors in solar projects could apply a loan with the Viet Nam Development Bank of up to 70% of the total investment capital (exclusive of working capital with a maximum tenor of 12 years) (Asian Power, 2017).

- Challenges in meeting future target

The issuance of Decision No. 11 and the draft circular, including the draft on the PPA for solar energy generation, are encouraging steps that can draw in more investment in solar installations (Baker McKenzie, 2017). However, there are some key issues that the draft circular has not resolved but may impact the bankability of solar projects and leave 'grey areas' for project developers. Rising concerns over the unclear sections of the draft circular include:

1) There is no provision to address the inflation risk nor are there rules on adjustment in the FiT if the exchange rate changes;
2) In the draft PPA, there is no stated compensation or payment to the project developer if Vietnam Electricity Corporation, as the purchaser, is given the rights to stop purchasing electricity under certain circumstances;
3) No provision for government guarantee or assurance to enhance creditworthiness of Vietnam Electricity Corporation as the off-taker;
4) No provision to address the risk of changes in law or tax and the payment protection in political *force majeure*.

- Plan for absorbing fluctuating power output from solar

Viet Nam has just established the FiT for solar energy generation in 2017. In the next years, investment in solar energy is predicted to take off, accompanied by additional solar capacity. At this point, the need to set up storage systems to address the intermittency is not urgent given that Viet Nam's solar capacity in the grid is not big enough. However, considering the attractive FiT scheme, the addition in solar capacity is predicted to increase rapidly in the future.

Chapter 3

Characteristics of Storage Technologies

3-1 Overview of Energy Storage Technologies

Major energy storage technologies today can be categorised as either mechanical storage, thermal storage, or chemical storage. For example, pumped storage hydropower (PSH), compressed air energy storage (CAES), and flywheel are mechanical storage technologies. Those technologies convert electricity to mechanical energy.

Thermal storage technologies convert electricity into thermal energy (hot water, ice) for heating or cooling purpose, or absorb and store renewable heat and use the heat for power generation (concentrated solar power).

Batteries are chemical storage technologies using electro-chemical reaction to store (charge) or release (discharge) electricity. Chemical storage technologies also include hydrogen (although this has other applications besides energy storage).

Pumped storage hydropower is the most mature energy storage technology and has the largest installed capacity at present. However, given their flexibility and continuing cost reduction, batteries are rapidly increasing their share of the energy storage market. The choice of energy storage technologies to use depends on the technologies' characteristics vis-à-vis specific requirements from energy services.

In this chapter, the following terms and definitions are used:

Power rating (or rated output/size, kW) is the instantaneous demand requirement the storage module can supply.

Energy capacity (kWh) is the total amount of energy the storage module can deliver.

E/P ratio is the storage module's energy capacity divided by its power rating (= energy capacity/power rating). The E/P ratio represents the duration (hours, minutes, or seconds) the storage module can operate while delivering its rated output.

3-2 Characteristics of Selected Energy Storage Technologies

(1) Pumped storage hydropower

Pumped storage hydropower is a mature technology. It stores electricity in the form of gravitational potential energy. There are two reservoirs of different heights. When electricity demand is low, water is pumped from the lower reservoir to higher reservoir. During discharging, water is released from the higher reservoir to the lower reservoir, passing through turbine for electricity generation.

Until mid-2017, global PSH capacity was around 170 GW, which represents more than 95% of the total energy storage capacity. About half of the PSH capacity is in China (32.1 GW), Japan (28.5 GW), and the United States (24.2 GW).

At present, PSH is mainly used for time shifting of electricity energy; that is, storing electricity when demand is low (for example, during night time) and discharging when demand is high. Other applications of PSH are supply capacity firming and black-start. Traditionally, PSH is used to maximise the economics of nuclear or thermal power generation. However, with the expanding deployment of variable renewable energy technologies such as solar PV and wind, the use of PSH dedicated to RE is also increasing.

Pumped storage hydropower can discharge for tens of hours economically and is capable of providing energy storage for days or even weeks. However, PSH plants require a large area of land and a high initial investment. Due to its size and location constraints, PSH is usually not feasible as on-site energy storage for small-scale renewable power generation plants.

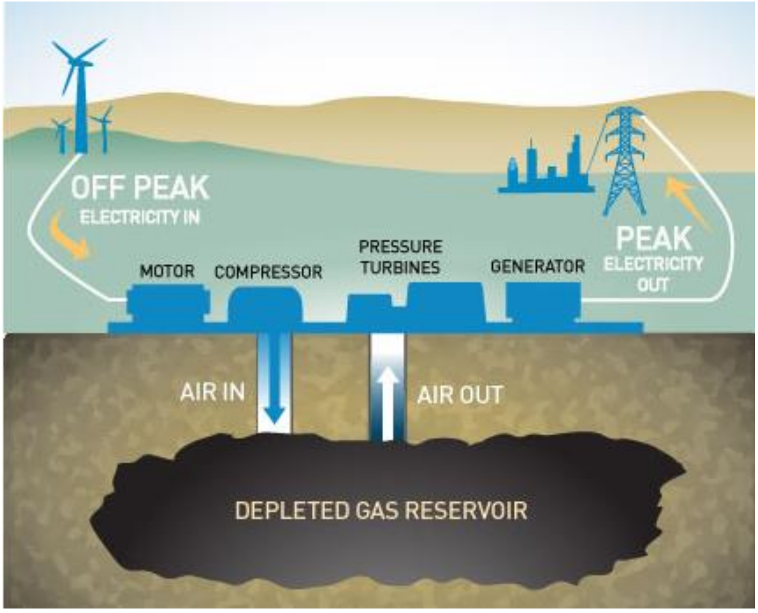
(2) Compressed Air Energy Storage (CAES)

Compressed air energy storage stores energy by compressing air in a cavern. In a CAES plant, ambient air is compressed and stored in underground caverns during off-peak periods, and the air is released to drive a gas turbine for electricity generation when electricity demand is high. Using existing suitable caverns such as depleted gas fields could significantly reduce the cost.

As of 2016, only two large-scale CAES plants are connected to the grid: one (290 MW) in Huntorf in Germany and the other (270 MW) in Alabama in the United States.

Similar to PSH, CAES is typically used for managing large amounts of energy. However, location constraints and high initial investment requirement limit CAES's applications.

Figure 3-1. Operation Mechanism of CAES



CAES = compressed air energy storage.

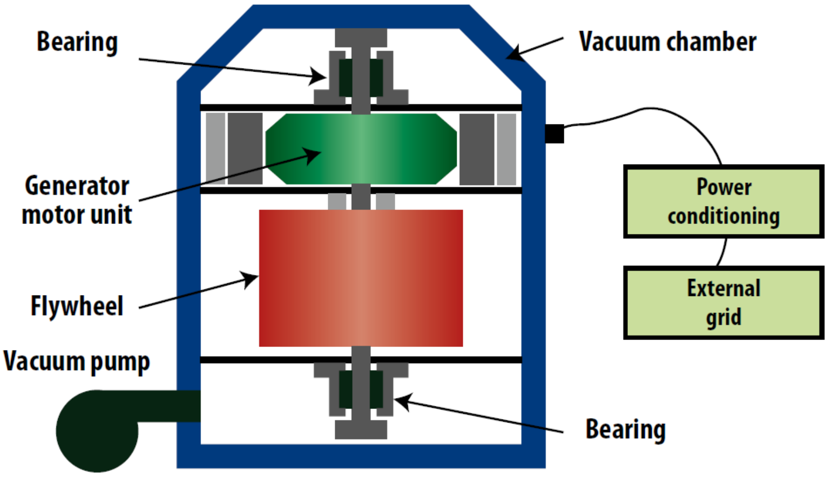
Source: Pacific Gas and Electric Company.

(3) Flywheel

Flywheels store energy in the form of rotational kinetic energy. The central part of the flywheel energy storage system is a rotating mass (flywheel). The rotating mass is accelerated during charging while the high-speed rotating mass will drive the generator motor during discharging. The energy that can be stored in the flywheel system depends mainly on the weight of the rotating mass and the speed at which it rotates.

Flywheel systems have very fast charging/discharging response and a high rated power. However, because of its high self-discharging rate, the discharge time at rated power for flywheels usually takes seconds long, which means that the energy density of flywheel is low. Given these characteristics, the flywheel is suitable for applications that require high response speed and high power such as frequency response. Applications like energy shifting, which requires higher energy density (i.e. longer discharge time at the rated power) is not the match for flywheels.

Figure 3-2. Flywheel Energy Storage System



Source: IRENA (2017).

(4) Ice storage

Ice storage keeps electricity in the form of cold energy. When electricity demand is low, the ice storage system uses electricity to produce ice that can be used for space cooling. Using stored ice for cooling could help save the fuel that would otherwise be consumed for cooling purpose.

Ice storage is a demand-side energy management measure for energy shifting in buildings. Ice storage is typically employed to produce ice during midnight, when electricity price is low; and to cool the building during daytime, when electricity tariff is high. Since the output of solar PV peaks during daytime, the combination of solar PV and ice storage is only economically suitable for buildings that have a cooling demand during the night or early in the morning (for example, households in tropical regions).

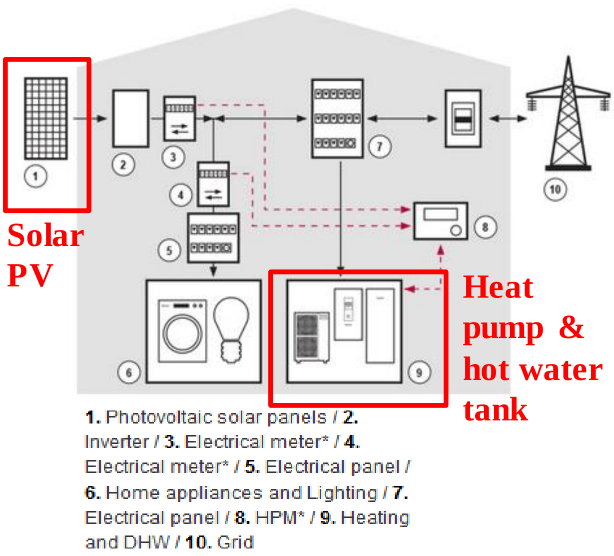
(5) Hot water storage

Electricity can also be stored in the form of hot water, which will require an electric water heater and a water tank. The electric water heater can be traditional electric resistance water heaters or heat pump water heaters.

Heat pump water heaters can use a small amount of power to move a larger amount of thermal energy for space heating, space cooling, and/or water heating. They use electricity to move heat from one place to another rather than generating heat directly and is more efficient than traditional water heaters using electric resistance.

Combining solar PV with heat pump (i.e. with hot water tanks) can not only provide clean electricity for buildings but also reduce the buildings' energy demand for heating. In particular, heat pump water heaters with hot water tanks can store huge solar power during the daytime and help improve the self-consumption rate of rooftop solar PV panels.

Figure 3-3. Example of Solar PV and Heat Pump System for Home Energy Supply

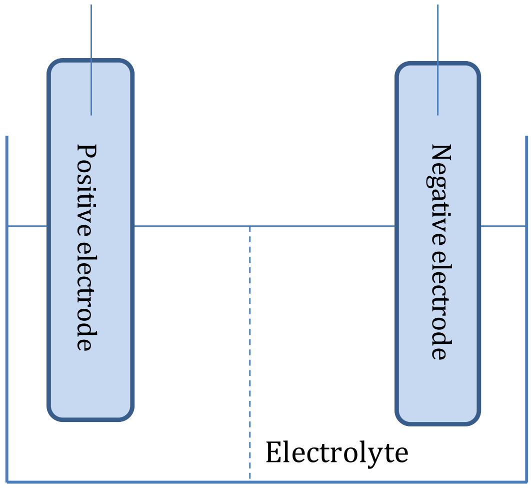


Source: Panasonic website.

(6) Batteries

The basic structure of batteries consists of a negative electrode (cathode), a positive electrode (anode), and the electrolyte. In its electro-chemical reaction, electrons (–)/ions (+) moving between the two electrodes pass through the electrolyte. Charging and discharging represent opposite direction of the electrons (–) or ions (+)'s movement. Batteries in the market vary based on their material and the design of the cathode, anode, and electrolyte. They vary significantly in characteristics such as energy density, power density, life span, safety, and cost.

Figure 3-4. Basic Structure of Batteries



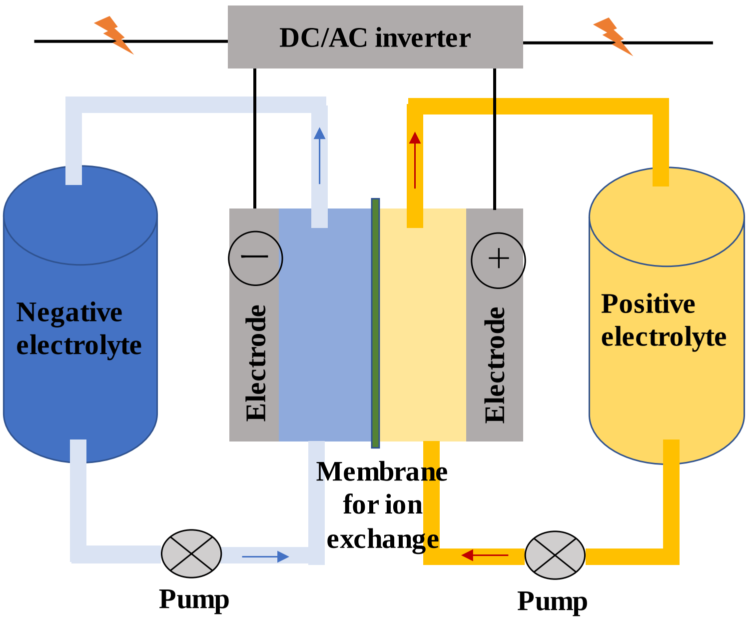
Source: Authors.

Lead-acid batteries are the oldest and most widely deployed rechargeable battery. Their installation cost is the lowest amongst all the current battery technologies. However, the energy density of lead-acid batteries is relative low, and the cycle life is shorter than most other types of batteries.

Given its high energy density, Lithium-ion (Li-ion) batteries are widely used in consumer electronics. In recent years, Li-ion battery installations have seen rapid growth in other fields such as electrical vehicles and stationery storage. Besides having a high energy density, Li-ion batteries also exhibit advantages such as high power density, good round-trip efficiency, relative long lifetime, and low self-discharge rate. However, issues with Li-ion batteries such as thermal stability and safety still persist.

With the increasing need to maintain the grid's stability as more variable REs connect to grids, batteries with large capacity such as flow batteries are also emerging in the market. Unlike traditional battery designs, which hold the electroactive materials at the electrodes, flow batteries store electroactive materials in the electrolyte solutions (Figure 3-5). Since the electrolyte and electrodes are separately stored, the energy capacity and rated power of flow batteries can be adjusted independently according to the specific requirement of the application.[2] Flow batteries can provide large energy capacities for large-scale applications and have longer cycle lifetimes than other technologies. However, the round-trip efficiency of flow batteries is lower than that of Li-ion batteries. Also, the system design of flow batteries is more complex.

Figure 3-5. Mechanism of Flow Battery



Source: Authors.

High temperature batteries – where the NaS battery and $NaNiCl_2$ battery (also known as ZEBRA) are the best-known commercial types – are also being used for grid services. High temperature batteries have an energy density higher than that of flow batteries but still lower than the average level for Li-ion batteries. They have installation costs that can compete with that of Li-ion batteries and longer cycle lifetimes than most Li-ion batteries.

(7) Hydrogen

Renewable electricity can be absorbed by producing hydrogen through water electrolysis. Hydrogen is a promising option for large-scale, long-term, and seasonal renewable storage.

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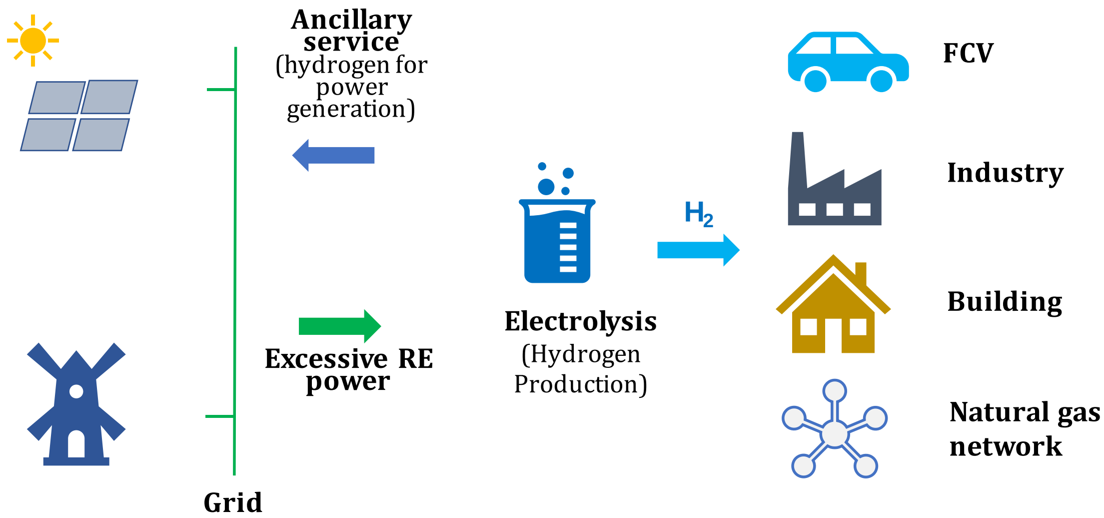
[2] The rated power can be scaled by increasing the electrode surface, while the energy capacity can be expanded by increasing the volume of electrolyte in the tank.

Since hydrogen does not emit carbon at usage, it has the potential to replace fossil fuel in many final energy applications such as transportation (Fuel cell vehicles, industries (both as industrial gas and as fuel), and heating for buildings. Hydrogen can also be injected into natural gas pipelines (up to a certain percentage) and is used for power generation either through fuel cells or hydrogen turbine (note: not commercialised yet).

With the increasing deployment of variable renewable technologies, the concept of 'power-to-gas' (Figure 3-6) as an energy of the future is drawing much attention. Pilot projects are underway in Japan, Europe, and the United States. However, the power-to-gas concept of the future requires technology breakthrough, commercialisation and cost reduction, and new infrastructure to be in place before it can be realised.

Figure 3-6. Image of Power-to-Gas System



Source: Author.

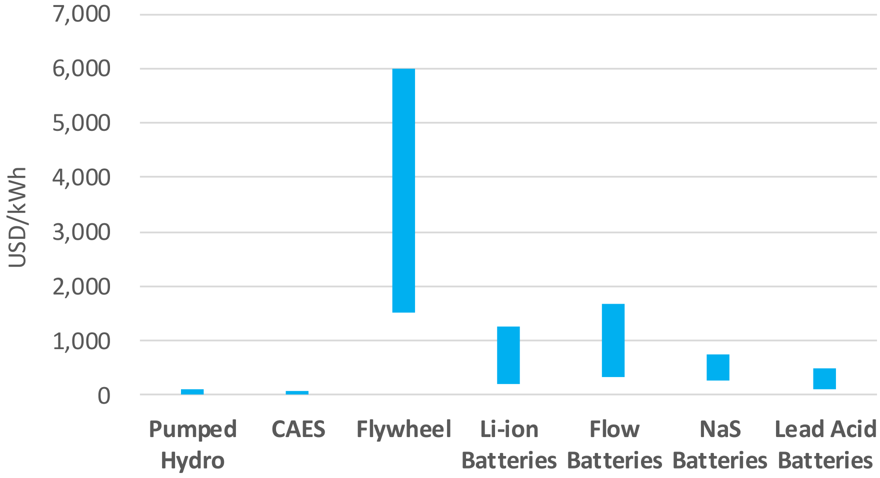
3-3 Overview of Cost and Characteristics of Various Energy Storage Technologies

(1) Cost

Data on installation costs of various storage technologies are well documented (Figure 3-7). However, that of the levelised service cost (i.e. the cost per kWh of power generation) is dependent on the cycle lifetimes of the storage technology and its operational pattern.

Pumped storage hydropower stands out as the technology with the lowest unit installation cost (US$/kWh).[3] Its scale, however, is usually bigger than other technologies, which means that the total initial investment requirement per project using pumped storage hydropower is very high.

Figure 3-7. Unit Installation Cost of Various Storage Technologies as of 2016



Source: Compiled by author based on IRENA (2017).

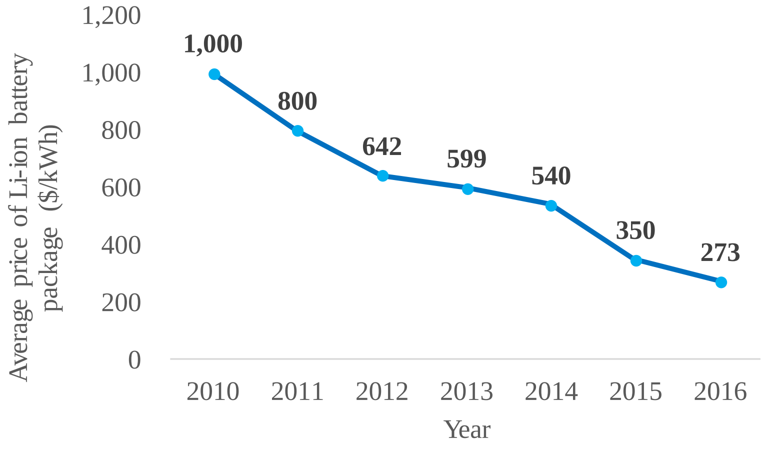
Prices of batteries, especially Li-ion batteries, have seen steep cost reductions in recent years (Figure 3-8). Such cost reduction is expected to continue in the future (Figure 3-9), driven by performance improvements, learning effects as well as economies of scale.

(2) Overview of characteristics of various energy storage technologies and applications

Different energy storage technologies are suitable for distinct applications. For example, when mapping various energy storage applications (stationery) and technologies by power capacity and discharge duration (Figure 3-10), one can see that while battery is suitable for various applications and almost have no site constraints, it is unable to provide inter-seasonal or seasonal energy storage. Hydrogen is the only technology that can hold seasonal energy storage.

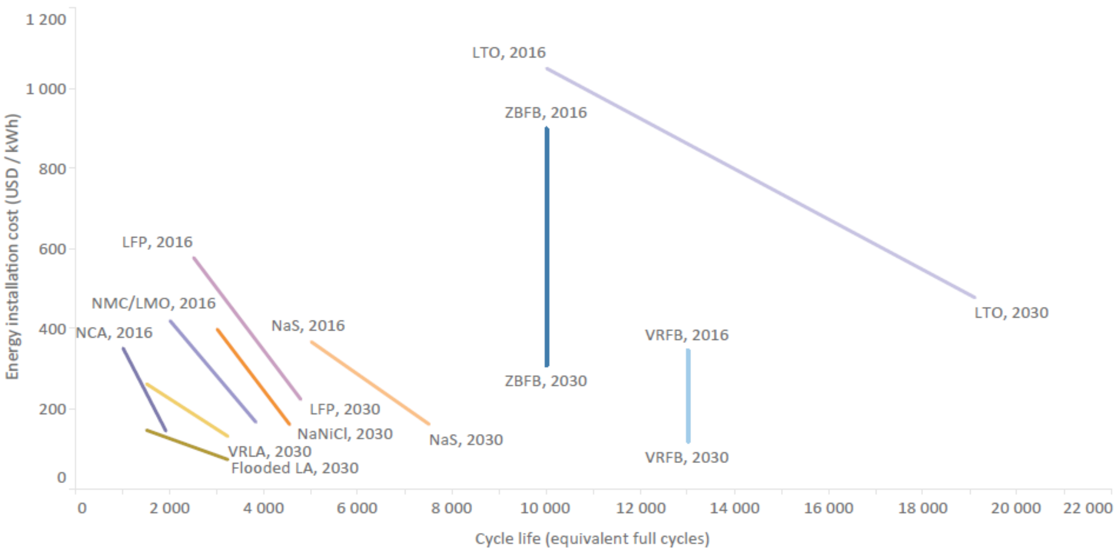
[3] 'kWh' here represents the capacity of energy storage rather than power generation.

Figure 3-8. Price Reduction of Li-Ion Battery From 2010 to 2016



Source: Bloomberg New Energy Finance (2017)

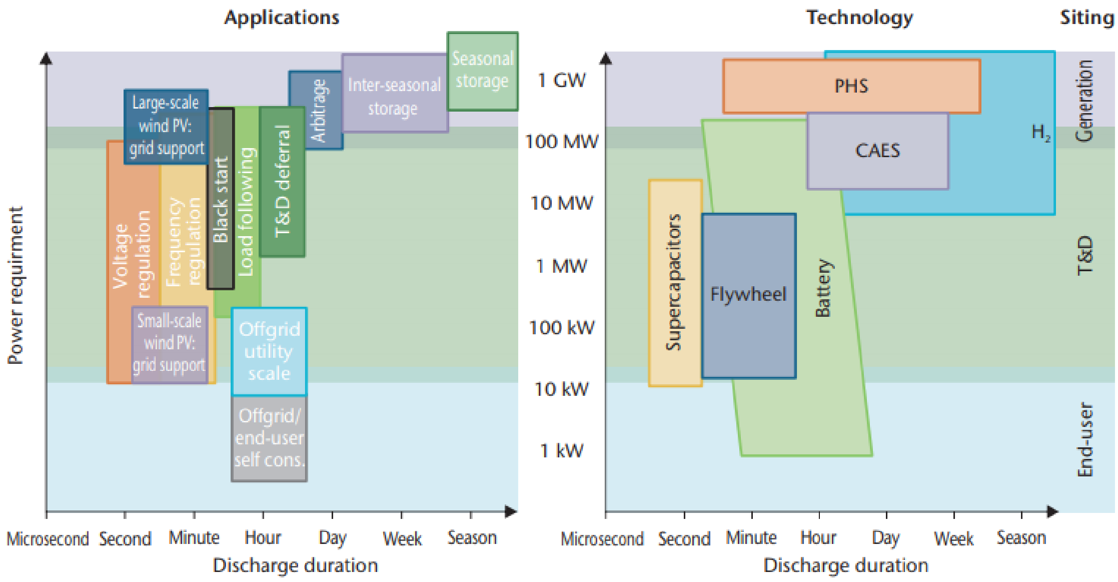
Figure 3-9. Cost Reduction and Cycle Life Improvement of Various Battery Technologies Through 2030



Note: Li-ion battery sub-technologies: NCA=nickel cobalt aluminium, NMC/LMO=nickel manganese cobalt oxide/lithium manganese oxide, LFP=lithium iron phosphate, LTO=lithium titanate; Flow battery sub-technologies: VRFB=vanadium redox flow battery, ZBFB=zinc bromine flow battery; High temperature battery sub-technologies; Lead-acid battery sub-technologies: VRLA=valve-regulated lead-acid, Flooded LA=lead-acid.

Source: IRENA (2017).

Figure 3-10. Mapping of Energy Storage Applications and Technologies by Power Capacity and Discharge Duration



Source: IEA (2015).

The choice of energy storage technology for a specific energy service need depends on many factors, including technology suitability, cost, service lifetime, space and location constraints, and safety considerations. For example, for mobile and consumer electronics application, high-energy capacity in a compact space is required, which means batteries with high energy density (kWh/litre) is preferable – even if it sometimes means a tradeoff with cost.

Besides discharging duration and cost, other characteristics of select storage technologies featured in this report are summarised in Table 3-1.

Table 3-1. Summary of Other Characteristics of Selected Storage Technologies (2016)

Storage technology	Round trip efficiency	Cycle life (full cycles)	Energy density (kWh/litre)	Self discharge (%/day)
Pumped storage hydro	80%	50,000	2	0.01
CAES	60%	50,000	2~6	0.5
Flywheel	84%	200,000	20~200	60
Li-ion batteries	>90%	1,000~10000	200~735	0.05~0.2
Flow batteries	70%	10,000~13,000	15~70	VRFB: 0.15 ZBFB: 15
NaS batteries	80%	5,000	140~300	0.05
Lead-acid batteries	80%	1,500	50~100	0.09

VRFB = vanadium redox flow battery; ZBFB = zinc bromine flow battery; CAES = compressed air energy storage; NaS = sodium sulphur.

Source: Compiled by author based on IRENA (2017).

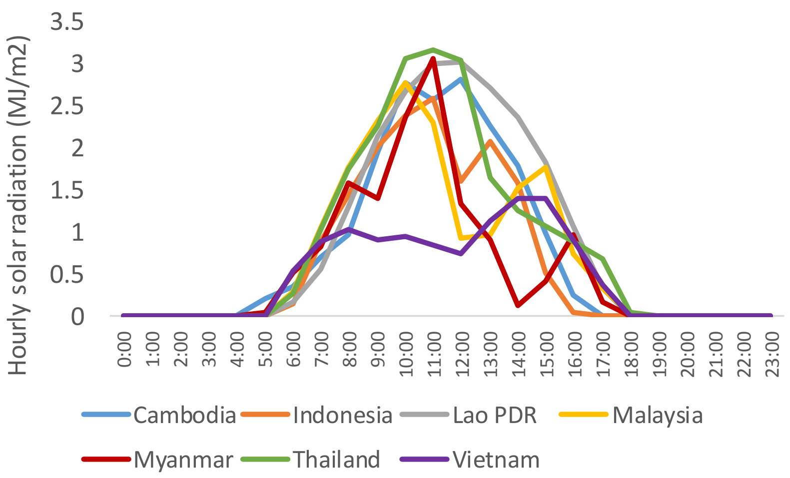
Chapter 4

Assessment of Storage Technologies for Solar PV

4–1 Analysis Overview

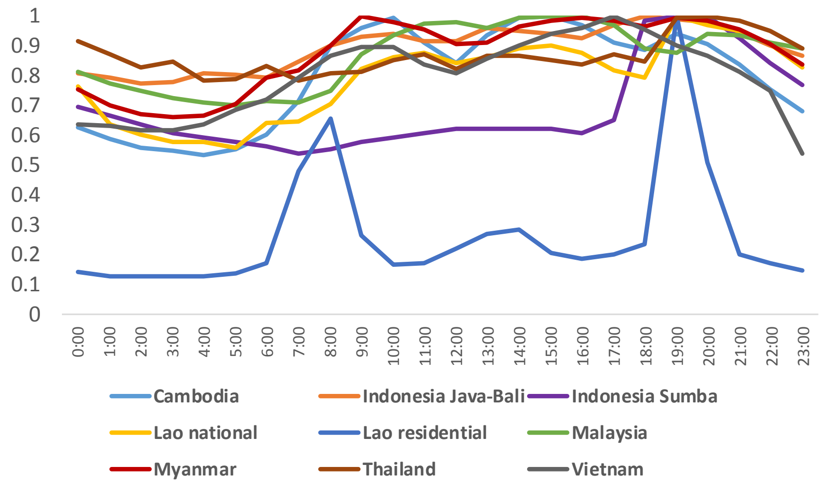
In the power system, the balance between electricity supply and demand must be maintained all the time. However, the output of solar PV depends on the solar radiation condition. That is, generation from solar PV cannot be adjusted according to the load condition and is difficult to predict.

Figure 4–1. Example of Hourly Solar Radiation in ASEAN Countries



Source: Compiled by author using data from New Energy and Industrial Technology Development Organization (NEDO).

Figure 4–2. Example of One-Day Load Curve (Normalised) in ASEAN Countries



ASEAN = Association of Southeast Asian Nations.

Source: Compiled by author using data from various sources including data provided by the participants at the first Assessment of Electricity Storage Technology for Solar PV workshop, data from previous ERIA study, as well as openly published data from utility companies.

Energy storage, especially batteries, is an effective solution to the mismatch between solar output and electricity load. With battery costs falling, the application of batteries – whether at the end-user's side or at the power plant's side – as a way to mitigate solar PV's intermittency in grids has seen rapid growth.

In the first workshop meeting for this study, participants showed great interest in the potential of solar PV and energy storage. At the meeting, three questions were the core of the discussions:

- *How much energy storage capacity will be needed for a certain amount of solar PV?*
- *What will be the economic viability of energy storage technologies?*
- *What are the implications for policymakers*?

The answers to these questions vary significantly depending on the power system and market contexts. For example, since the solar PV and energy storage system is connected to an integrated electricity system and the purpose of energy storage is to help maintain the balance of the whole system, the required energy storage capacity is affected by the load pattern and by how other power generation plants are operated. Therefore, to determine the capacity of energy storage, a complex simulation of the whole electricity system is required.

However, such simulation mentioned above always requires detailed data and information on the whole power generation fleet, the merit order of the generator's dispatching, as well as load pattern, etc. – information that is always not well documented or disclosed within most ASEAN countries. To simplify the calculation and reduce the data requirement, the conditions in which the solar PV and energy storage system operate are predefined in the analysis. Under the presumed cases, the required capacity and the economics of energy storage technologies are calculated.

4–2 Simulation Cases

Three cases are discussed in this study: two cases on utility-scale solar PV power plants, and one case on the household rooftop PV system.

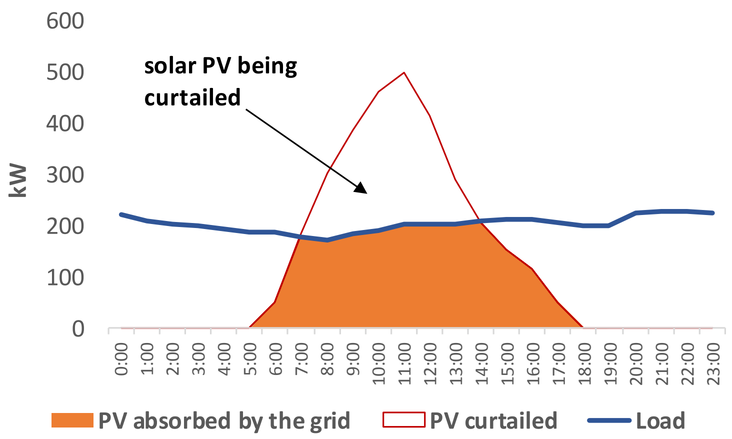
Case 1: Curtailment avoidance (utility-scale solar PV)

The magnitude of solar PV output varies largely within one day. At its peak, the output of solar PV could be higher than what the grid can absorb. To maintain the balance between supply and demand, the excess is usually curtailed (i.e. thrown away) if storage is not available (Figure 4–3). Curtailment leads to less electricity sold to the grid and will ruin the revenue of the solar PV developer. Thus, the high curtailment rate of solar PV is naturally one of investors' emerging concerns.

If an energy storage facility is available, the excess solar PV that cannot be absorbed by the grid may be stored and later released to the grid when solar PV output is low (Figure 4-4). By levelising the output of solar PV using an energy storage system, the effective power generated[4] could increase. However, because of energy losses during charging and discharging, and of the self-discharge of energy storage facilities, not all power generated by the solar PV plants can be fed into the grid.

[4] Solar PV power generation that is absorbed by the grid.

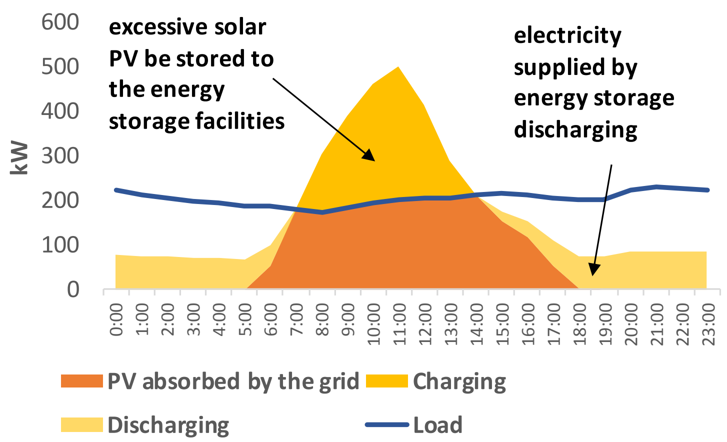
Figure 4-3. Curtailment of Solar PV



PV = photovoltaics.

Source: Author, based on the load and solar radiation data of Malaysia.

Figure 4-4. Using Energy Storage To Absorb the Excessive Solar PV



Source: Authors' analysis based on the load and solar radiation data of Malaysia.

Although the installation of an energy storage facility requires additional investment, the effective solar power generated will also be increased. As a result, if the cost of energy storage facility is low enough, the levelised effective power generation cost (that is, the cost levelised by the power fed into the grid) could be cheaper than that without energy storage (under which case the excess solar PV is curtailed).

The required storage capacity for absorbing all the excess solar PV power is calculated in a simulation study under various curtailment rate assumptions. The curtailment rate of solar PV represents how much of the annual solar PV generated would be curtailed without energy storage. It is calculated using the following equation:

Solar PV curtailment rate *= amount of annual curtailed solar PV/annual total solar PV output*

The economics of energy storage in this case is evaluated by comparing the effective power generation cost (i.e. levelised cost of electricity [LCOE]) of two conditions: (i) without energy storage; and (ii) with energy storage absorbing all the excess solar PV power. Three sets of system cost assumptions (Section 4-4) are applied to calculate the LCOE.

Effective solar PV generation is calculated as follows:

(1) Annual effective power generated without energy storage *= annual total solar PV output – annual total curtailed solar PV*

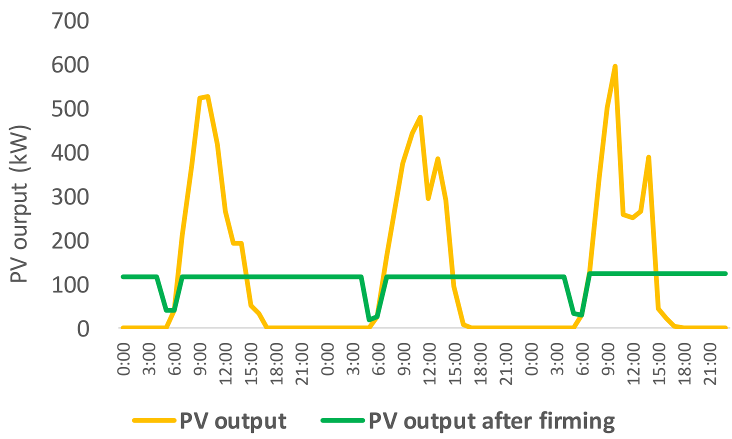
(2) Annual effective power generated with energy storage *= annual total solar PV output – annual total energy losses during charging and discharging – annual total self-discharge of energy storage facility*

Case 2: Capacity firming / output shaping (utility-scale solar PV)

In the management of electric power systems, most electricity demand and supply nowadays are balanced ahead of when the demand really happens. In this process, grid operators aim for a predicable and committed power supply ('firm' capacity) for their facilities. Since the power generation of solar PV relies on the condition of the solar radiation, its output is non-firm. The intermittency ('non-firm') of solar PV may lead to higher grid operation costs. This is, in fact, one of solar PV's disadvantages compared with conventional power generation technologies with firm capacity.

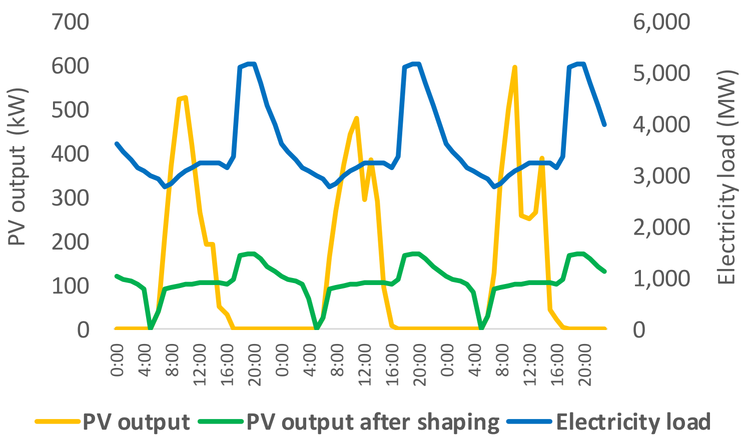
One of energy storage technologies' applications is renewable capacity firming. By charging (storing peak) and discharging (filling valley), the output of variable renewable technologies can be kept relatively constant (Figure 4-5) or be shaped to follow the load change (Figure 4-6). Paired with an energy storage system, the output of solar PV can be controllable and the possible burden to grid operation may be reduced significantly.

Figure 4-5. Output of Solar PV After Firming by Energy Storage



Source: Author's analysis based on the load and solar radiation data of Malaysia

Figure 4-6. Output of Solar PV after Shaping to Follow Load Change



Source: Authors' analysis based on the load and solar radiation data of Malaysia.

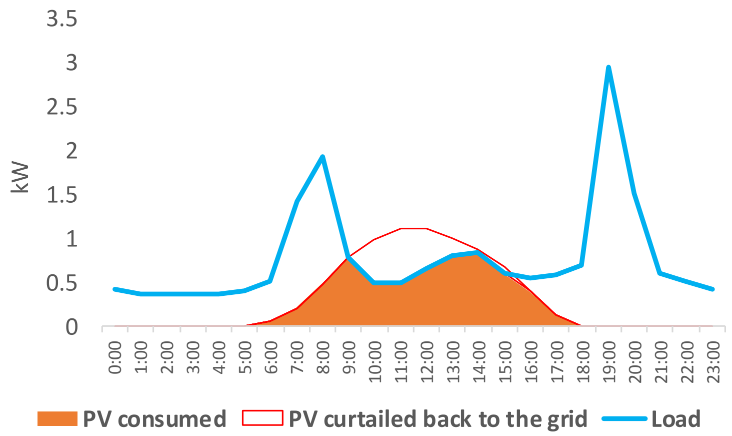
The technical disadvantage of variable renewable technologies can be compensated by pairing with energy storage systems, but this will also increase the cost of renewable power generation.

The simulation of this case aims to find out the energy storage capacity required if one were to shape the output of the overall system into a certain pattern. The economics of energy storage for solar PV capacity firming/output shaping will be evaluated by comparing the LCOE of solar PV + storage with that of conventional power generation technologies, or with wholesale electricity price. Two output patterns –constant output (firming) and load following – are presumed in this simulation. Note that in the first case, the output of solar PV is levelised on a daily basis rather than maintained constant over a whole year, as it is impossible to predict at the beginning of the year, the hourly solar PV output throughout the year.

Case 3: Residential solar PV + energy storage (Lao PDR)

Residential rooftop solar PV systems represent the bulk of the solar PV market in Germany and Japan, thanks to their government subsidy. In recent years, driven by the cost reduction of solar panels in places such as Australia, California, or Hawaii – where the solar radiation hours are long and electricity tariff is high – residential solar PV is becoming more popular and cost-competitive compared with electricity supplied by utility companies. However, the off-peak hour (around noon) for residential electricity demand is usually around the same time the output of solar PV peaks. As a result, a significant part of the electricity generated by rooftop solar PV could not be absorbed by the installer and has to be fed back to the grid (where net metering is allowed) or curtailed (where net metering is not allowed) (Figure 4-7).

Figure 4-7. Residential Solar PV Without Energy Storage

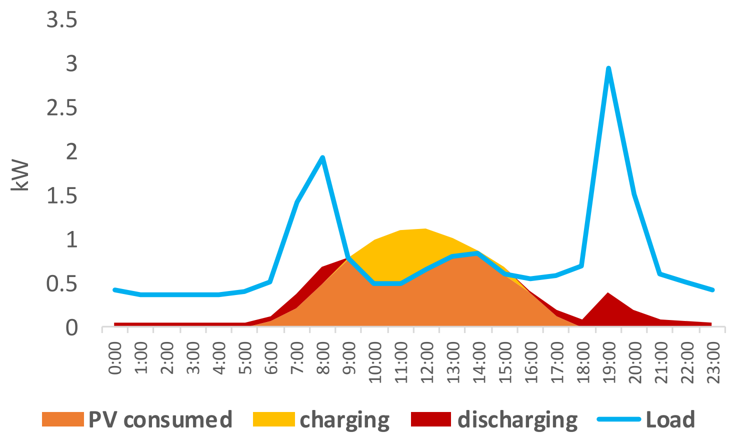


Source: Authors' study based on the load and solar radiation data of Lao PDR.

In places where net metering is not allowed because a significant part of residential solar PV cannot be effectively utilised (either by the household where the panel is installed or by other consumers through the grid), the whole system will be a waste of investment. Meanwhile, in places where net metering is possible, large amounts of solar PV output flowing into the power grid could disrupt the distribution grid's stability. To mitigate the impact on the grid, policies and programmes encouraging self-consumption of residential solar PV are implemented in places with high residential solar PV penetration.

With its price getting cheaper, batteries for residential installation are becoming popular in countries such as Germany or Australia, where the penetration of residential solar PV is high. By pairing with batteries, the excess solar PV power generated can be stored during the day and released during the evening and morning's peaks (Figure 4-8).

Figure 4-8. Residential Solar PV and Energy Storage



Source: Simulation results based on the load and solar radiation data of Lao PDR.

In this case, the self-consumption rate improvement for solar PV as enabled by the installation of batteries is evaluated. The economics of the residential solar PV + battery system is evaluated by comparing the system's power supply cost with the electricity tariff. The simulation of this case covers only Lao PDR because the household electricity demand load curve data is not available from the other countries.

4-3 Methodology

As mentioned earlier, rather than taking all factors into consideration, the simulation in this study focuses only on solar PV and energy storage. The required energy storage capacity is calculated by maintaining the solar PV + energy storage system's output to follow the change in the electricity demand or to form a certain output pattern. The required input data for this simulation consist of one year's electricity demand curve figures, hourly solar radiation data, and technology specifications of solar panel and energy storage technologies.

The solar PV output is calculated by referring to the solar radiation data and technology specification of the solar panel. The required output of solar + energy storage system is determined by using the electricity demand curve data and the assumptions for each simulation case. For example, for the curtailment avoidance case, the output is the adjusted electricity demand; for the capacity firming/output shaping case, the output is the daily constant or load following. Meanwhile, for the residential solar PV + energy storage, the system's output is determined by the household's electricity demand.

Once the required capacity of energy storage is determined, the power generation cost (or the LCOE) of the whole system is calculated using cashflow analysis method. The economics of energy storage is evaluated by comparing the LCOE of the solar PV + energy storage system with different benchmarks.

4-4 Preconditions and Assumptions

(1) Data availability

Data required for the simulation include hourly load curve data, hourly solar radiation data, technical specifications of energy storage facilities and solar panel. Technical specifications were assumed by the authors based on research reports or information published by manufacturers. The hourly electricity load data were collected from various sources (Table 4-1).

Table 4-1. Sources for Electricity Load Data and Solar Radiation Data

	Load curve	**Hourly solar radiation**
Cambodia	Compiled by IEEJ based on data provided by WS1 participant	NEDO
Indonesia	Java–Bali: Compiled by IEEJ from previous ERIA study (ERIA, 2014)	NEDO
	Sumba Island: Compiled by IEEJ based on Hivos report (Hivos, 2011)	
Malaysia	Compiled by APERC based on TNB published data	NEDO

Myanmar	Compiled by IEEJ based on data provided by WS2 participant	NEDO
Lao PDR	Compiled by IEEJ based on previous ERIA study (ERIA, 2014) and data provided by WS 1 participant	NEDO
Thailand	Compiled by IEEJ based on previous ERIA study (ERIA, 2014) and research paper by Baird and Quastel (2015)	NEDO
Viet Nam	Compiled by IEEJ based on data previous ERIA study (ERIA, 2014)	NEDO

APERC = Asia Pacific Energy Research Center; IEEJ = Institute of Energy Economics, Japan; NEDO = New Energy and Industrial Technology Development Organization; TNB = Tenaga Nasional Berhad; WS1 = First Workshop.

Note: *1 TNB: Tenaga Nasional Berhad (largest electricity utility company in Malaysia)

Source: Author.

To reflect the difference in the patterns in electricity load and solar radiation during different seasons or on workday and weekend, the observed data for one whole year is desirable. However, in most ASEAN countries, hourly electricity load data are not disclosed, thus a compromise has to be made by using data samples covering a short period within the whole year (Table 4-2).

Table 4-2. Details of Electricity Load Curve Data

	Load curve type	**Data details**
Cambodia	National	Observed data for one month One week's average daily load curve data are applied to the other months
Indonesia	Java–Bali and Sumba Island	Java–Bali: Two patterns (dry season and rainy season) for the whole year
		Sumba Island: Two patterns (dry season and rainy season) for the whole year
Malaysia	Peninsula Malaysia	Observed data for a whole year

Myanmar	Yangon	Observed data for three months of different seasons (cool, hot, rainy) One week's average daily load curve data are applied to the other months by season
Lao PDR	National load curve and residential load curve	National: Two patterns (dry season and rainy season) for the whole year
		Residential: daily load curve from survey, which is applied to the whole year
Thailand	National load curve	Nine patterns for the whole year: workday, Saturday, and Sunday by three seasons (cool, hot, rainy)
Viet Nam	National load curve	Two patterns (dry season and rainy season) for the whole year

Source: Authors.

Hourly solar radiation data are compiled based on the database of the New Energy and Industrial Technology Development Organization. Conditions of solar radiation could vary significantly even within one country. However, because of the constraint on data availability, the geographical differences in solar radiation data inside one country is not considered in this simulation. For countries where there are missing data, the time slot with missing data were filled out by using values of the same time slot from another day.

Because of issues with data availability, not all ASEAN countries are covered in the simulation. For some countries (Indonesia and Lao PDR), there is more than one case. It should also be noticed that since arrangements have to be made to complete the missing data for hourly load curve and solar radiation, not all the input data for the simulation are observed data.

(2) Cost assumptions on solar PV and energy storage technologies

Three cases of costs for solar PV and energy storage are assumed in this study. One is based on the current price level; another is based on mild cost reduction from current averages; and the last one is based on expected future cost reduction (Table 4-3). Some of the cost assumptions in the second case have been observed to be already happening in other countries, although outside of the ASEAN region.

Table 4-3. Cost Assumptions for Solar PV and Energy Storage

	Assumption 1: Current price level	Assumption 2: Based on mild cost reduction	Assumption 3: Based on future cost reduction
System cost of utility-scale solar photovoltaic (US$/kW)	1,500	1,000	500
System cost of utility-scale solar photovoltaic (US$/kW)	1,800	1,000	500
Installation cost of battery (US$/kWh)	600	300	100
Installation cost of pumped storage hydropower (US$/kWh)	21	21	21

Source: IRENA (2018); IRENA (2017).

For the utility solar PV, two energy storage technologies – battery and PSH – are covered in the simulation. However, simulation of solar PV + PSH is only carried out for countries with information on PSH projects, either planned or ongoing. For residential solar PV, battery is the only technology considered. Current price and future cost reduction data are from various studies. Assumptions for the mild cost reduction case are set by referencing to low-cost cases being reported. Cost assumption for PSH are set constant for all cases.

4-5 Major Results

Case 1: Curtailment avoidance (utility-scale solar PV)

(1) Required capacity of energy storage

The required energy storage (battery) capacity that prevents curtailment of solar PV under various curtailment rate assumptions are summarised in Table 4-4. Although both the required capacity of battery and of PSH (i.e. only for countries with PSH project information: Indonesia, Thailand, and Viet Nam) were calculated, there were not much differences in the results for the two technologies. Thus, only the results of the battery case are shown here.

Table 4-4. Battery Capacity (kWh) Required to Absorb the Excess Solar PV Under Select Curtailment Rate Assumptions

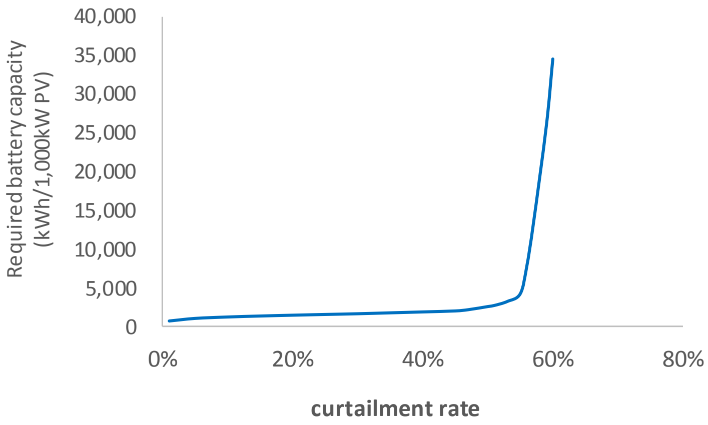
	Required battery capacity (kWh battery/kW PV)				
	Curtailment Rate 20%	Curtailment Rate 30%	Curtailment Rate 40%	Curtailment Rate 50%	Curtailment Rate 55%
Cambodia	1.9	2.3	2.7	8.3	33.3
Indonesia Java–Bali	1.3	1.5	1.7	1.9	2.0
Indonesia Sumba	1.3	1.5	1.7	1.9	2.0
Lao PDR	1.3	1.6	1.8	2.1	15.2
Malaysia	1.5	1.6	1.9	2.6	4.2
Myanmar	1.4	1.8	2.2	4.2	22.0
Thailand	1.4	1.6	1.9	2.2	6.3
Viet Nam	1.1	1.4	1.6	18.5	44.5

Source: Authors' calculation.

The difference in required battery capacity across countries per curtailment rate can be attributed mainly to the magnitude of their solar radiation. The curtailment rate represents the share of annual curtailed solar PV power generated in the total annual solar PV output. For the same solar PV capacity, places with higher solar radiation will generate more power from solar PV (thus, will have higher curtailed solar PV). Therefore, in terms of the required energy storage capacity per kW of solar PV, more capacity is needed in places with stronger solar radiation.

Simulation results also show that the required energy storage capacity increases mildly with curtailment rate until a certain point. Beyond that point, for every curtailment rate increase, a much larger energy storage capacity is required (Figure 4-9).

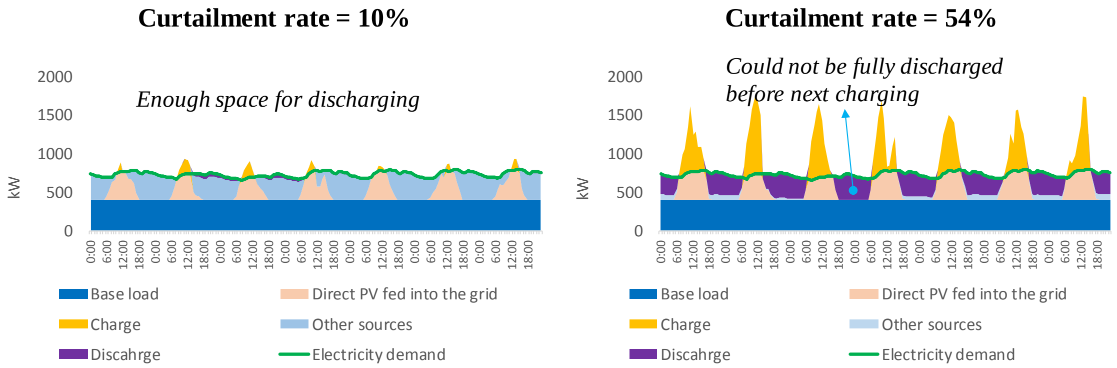
Figure 4-9. Required Battery Capacity per 1000 kW Solar PV By Curtailment Rate Assumption (Example of Malaysia)



Source: Author.

The solar PV stored in the energy storage facility needs to be released to the grid before next charging. When curtailment rate is low, the power stored is also low and the space in the grid to accommodate the discharged power before next charging is enough. However, with the rise in the curtailment rate, the power stored also rises. If the amount of stored solar power exceeds the grid's available capacity to absorb all the need-to-be discharged power, the energy stored in the energy storage system could not be fully released before the next charging. Therefore, larger and larger capacity will be required to store the excess solar PV because the electricity could not be fully discharged from the previous cycle.

Figure 4-10. Battery Charging and Discharging with 10% and 54% Curtailment Rate Assumptions (example of Malaysia)



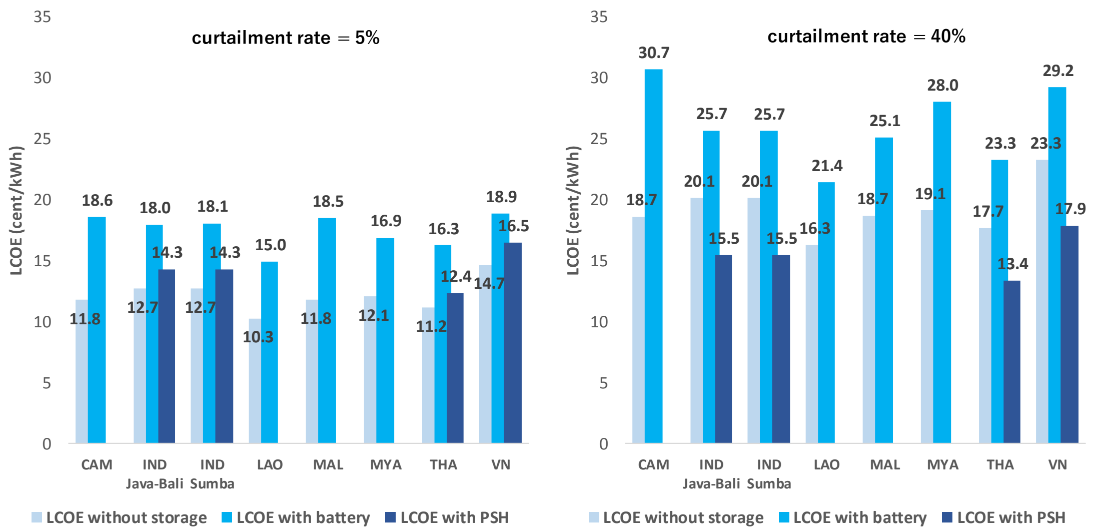
Source: Authors' calculations.

(2) Economics of energy storage

The economics of energy storage is evaluated by comparing the power generation cost (i.e. the LCOE) with and without energy storage. As mentioned above, when calculating the LCOE, the capital expenditure (CAPEX, the initial investment) is levelised by the electricity that will be effectively utilised. The effective electricity output in the solar PV + energy storage system is higher than that in the case with no energy storage (because of curtailment). Therefore, although adding the energy storage system to the solar PV power plant will lead to CAPEX increase, the levelised power generation cost could be lower. The LCOEs of solar PV without energy storage, solar PV + battery, and solar PV + PSH under curtailment rates of 5% and 40% are shown in Figure 4-11 to Figure 4-13, with each figure representing one set of cost assumption.

Figure 4-11. LCOEs With and Without Energy Storage

(PV = US$1,500/kW, battery = US$600/kWh, PSH = US$21/kWh)

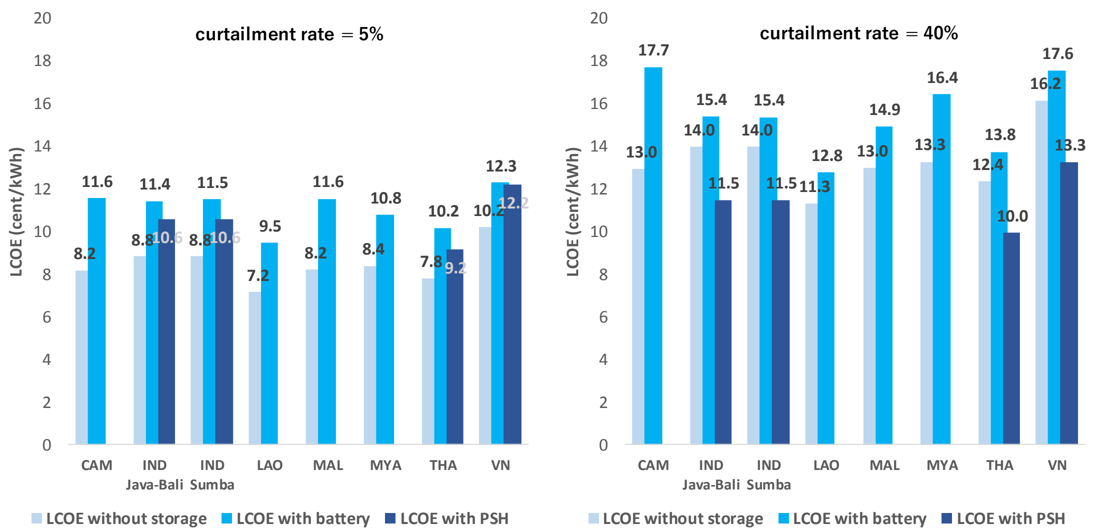


LCOE = levelised cost of electricity; CAM = Cambodia; IND = Indonesia; LAO = Lao PDR; MAL = Malaysia; MYA = Myanmar; THA = Thailand; VN = Viet Nam.

Source: Authors' calculation.

Figure 4-12. LCOEs With and Without Energy Storage

(PV = US$1,000/kW, battery = US$300/kWh, PSH = US$21/kWh)

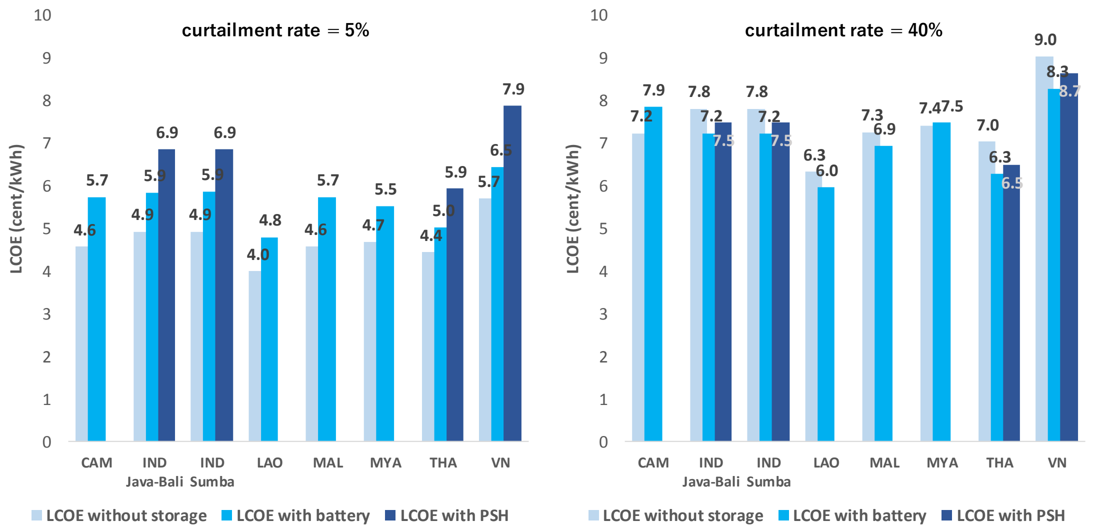


LCOE = levelised cost of electricity; PSH = pumped storage hydropower; CAM = Cambodia; IND = Indonesia; LAO = Lao PDR; MAL = Malaysia; MYA = Myanmar; THA = Thailand; VN = Viet Nam.

Source: Author's calculation.

Figure 4-13. LCOEs With and Without Energy Storage

(PV = US$500/kW, battery = US$100/kWh, PSH = US$21/kWh)



LCOE = levelised cost of electricity; PSH = pumped storage hydropower; CAM = Cambodia; IND = Indonesia; LAO = Lao PDR; MAL = Malaysia; MYA = Myanmar; THA = Thailand; VN = Viet Nam.

Source: Authors' calculation.

Solar PV + energy storage becomes more cost competitive when curtailment is higher. This is because high curtailment rate means less effective power generation (thus, high levelised power generation cost). Since the unit CAPEX of PSH is lower, solar PV + PSH is more cost competitive than solar PV + battery when the cost of battery is still high. However, it should be noted that the capacity of a PSH plant is usually much larger than that of battery, which means that all the PSH plant's capacity being dedicated to one solar PV power plant is highly unlikely. In this study, when calculating the LCOE of solar PV + PSH instead of CAPEX of the whole PSH plant, only the CAPEX for the capacity being utilised is counted.

Although the unit CAPEX of PSH is much lower than that of battery, the PSH's round-trip efficiency is lower than of batteries. Thus, more electricity will be lost during the charging/discharging process of PSH than that of batteries. In addition, because of its complexity and large size, PSH has a much higher operation and maintenance cost than do batteries. When the cost of batteries becomes low enough, the solar PV + battery will become more cost competitive than solar PV + PSH (Figure 4-13).

The cost competitiveness of energy storage under various assumptions of curtailment rate for each country/region is shown in the Annex of this publication. Figure 4-14 further depicts the evolution of the difference in LCOEs between solar PV + energy storage and solar PV without energy storage when there is an increase in curtailment rate. When the difference is larger than zero, LCOE of solar PV + energy storage is higher than that of solar PV without energy storage. This means that adding energy storage to avoid curtailment is not economically viable.

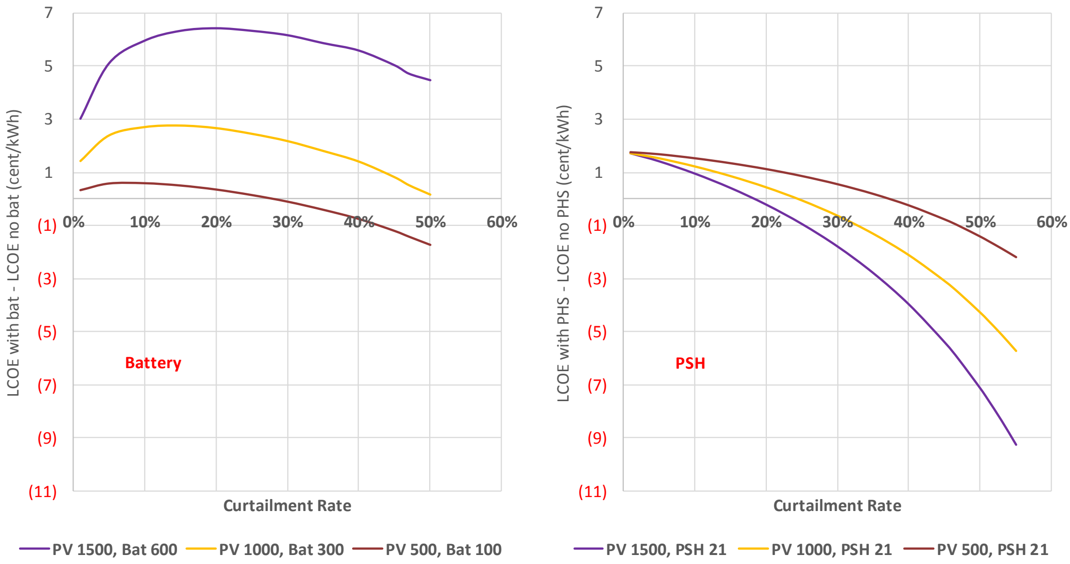
On the other hand, when the curve goes into the negative range, energy storage for curtailment avoidance is more cost competitive even when the initial investment is higher.

Case 2: Capacity firming/output shaping (utility-scale solar PV)

(1) Required capacity of energy storage

Simulation results on the required battery capacity per kW of solar PV for capacity firming and for output shaping (load following pattern) are presented in Table 4-5. As with Case 1, calculations were done for both the cases of battery and PSH, but because both presented similar results, only the findings on batteries are discussed in this report.

Figure 4-14. Evolution of Economic Viability of Energy Storage for Curtailment Avoidance (Example of Thailand)



Source: Authors' calculation.

Table 4-5. Required Battery Capacity (kWh) per kW of PV for Capacity Firming and Load Following

	Required battery capacity (kWh battery/kW PV)	
	Capacity firming	Load following
Cambodia	2.5	2.4
Indonesia Java–Bali	2.0	2.0
Indonesia Sumba	2.0	2.1
Lao	2.2	2.1
Malaysia	2.0	2.1
Myanmar	2.3	2.2
Thailand	2.2	2.1
Viet Nam	1.8	1.7

kWh = kilowatt-hour; kW = kilowatt; PV = photovoltaics.

Source: Author's calculation.

In the capacity firming case, the solar PV + energy storage system has a daily constant output, to smoothen out what is originally a reverse bell-shaped solar PV output (on a sunny day). However, since the firming is done on a daily base, the magnitude of output from day to day could be different depending on that day's solar radiation condition.

In the load following case, the required energy storage capacity is determined by the solar PV output pattern and electricity load curve.

It should be noticed that since the firming is carried out on a daily base, the result represents the maximum value of each day's energy storage requirement in one year.

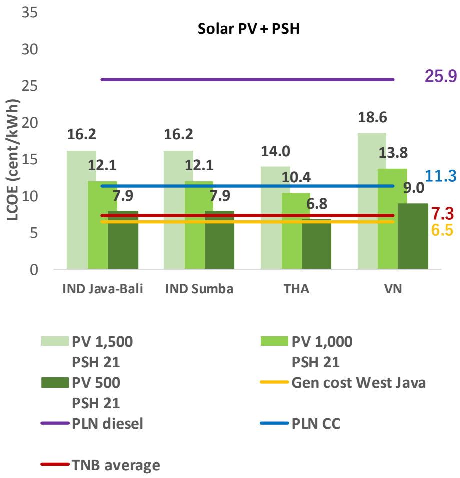
(2) Economics of energy storage

Paired with energy storage, the output of solar PV can be controllable, thus giving it an overall advantage over conventional power generation technologies.

At current average solar PV and battery price levels, the LCOE of solar PV + battery system in most ASEAN countries is higher than US$0.26/kWh, which is even higher than the LCOE of diesel power generators in some countries. However, with the solar PV cost of US$1,000/kW and battery cost of US$300/kWh, the system's LCOE can be reduced to less than US$0.18/kWh, which is lower than that of diesel power generators in some countries but still more expensive than conventional power generation technologies. If further cost reduction of both solar PV and battery is realised (i.e. solar PV at US$500/kW, battery at US$100/kWh), the output controllable solar PV + battery system can be as competitive as conventional power generation technologies in most ASEAN countries.

If PSH is available, the solar PV + PSH system could achieve lower LCOE with the same output pattern as that of solar PV + battery. However, for the same solar PV system cost but where the battery cost is reduced to US$100/kWh, results show that the power generation cost of the two options will be at the same level.

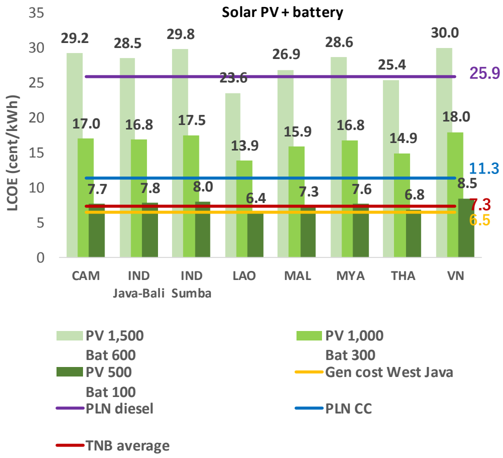
Figure 4-15. LCOE of Solar PV + Energy Storage for Daily Capacity Firming

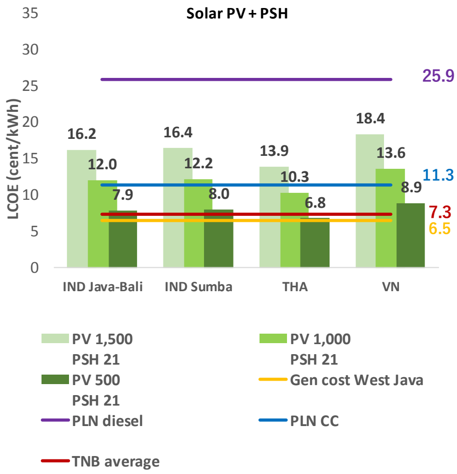


CC = natural gas combined cycle; PSH = pumped storage hydropower; PLN = Perusahaan Listrik Negara (Indonesian government owned utility company); PV = photovoltaic; TNB =Tenaga Nasional Berhad (largest electricity utility company in Malaysia).

Source: Authors' calculation; ASEAN Centre for Energy (2016); Ministry of Energy and Mineral Resources of the Republic of Indonesia (2017).

Figure 4-16. LCOE of Solar PV + Energy Storage With Load Following Output





CC = natural gas combined cycle; PSH = pumped storage hydropower; PLN = Perusahaan Listrik Negara (Indonesian government owned utility company); PV = photovoltaic; TNB =Tenaga Nasional Berhad (largest electricity utility company in Malaysia).

Source: Authors' calculation; ASEAN Centre for Energy (2016); Ministry of Energy and Mineral Resources of the Republic of Indonesia (2017).

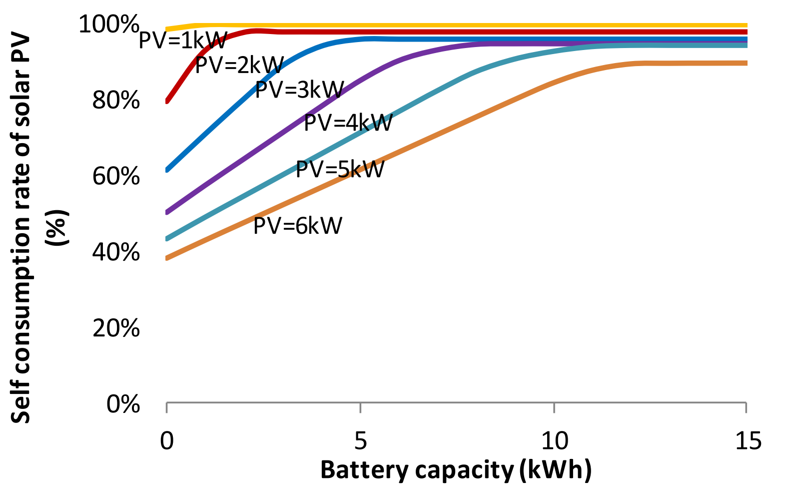
Case 3: Residential solar PV (Lao PDR)

(1) Improvement of self-consumption of residential solar PV

Power from residential solar PV systems that is fed back to the grid is one of the concerns in grid stability. In some ASEAN countries, net metering (fed-back power from household PV panels to the grid) is not even allowed. However, because the peak time of the solar PV output does not match the time when household electricity demand peaks, the self-consumption rate (i.e. the solar PV generation used by the consumer compared with the total solar PV power generation) of residential solar PV is usually low.

The self-consumption rate of residential solar PV can be effectively improved by pairing with battery storage systems. For a typical household in the suburban region near Vientiane in Lao PDR, the peak load is around 3 kW. If the household installs a 4 kW solar PV system, which is the average size of residential solar PV in Japan, the self-consumption rate would only be around 50% when there is no battery. However, the self-consumption rate can be improved to 85% with a 5 kWh battery (Figure 4-17).

Figure 4-17. Self-Consumption Rate of Various Solar PV and Battery Combinations



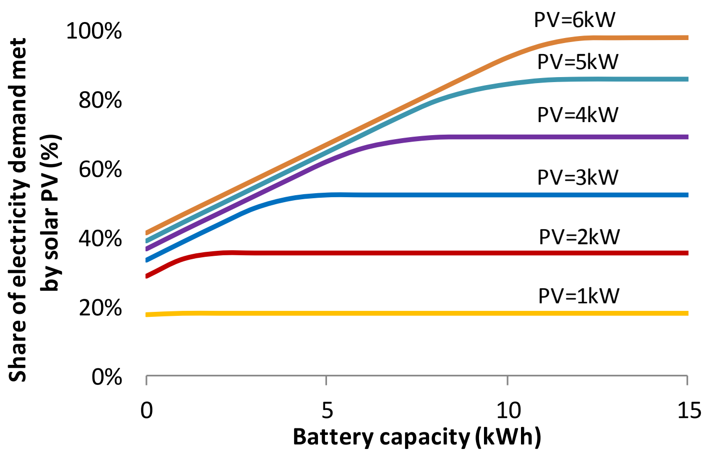
PV = photovoltaic; kWh = kilowatt-hour.

Source: Authors' calculations.

Figure 4-17 depicts the self-consumption rate under various solar PV + battery combinations of a household in Lao PDR with a peak electricity demand of 3 kW. For the same solar PV size, the self-consumption rate is improved by increasing the battery's capacity. However, because of the energy lost during charging and discharging, self-consumption rate settles at a certain level despite the additional battery capacity.

Although its self-consumption rate is low, bigger solar PV can supply larger output to the household's electricity demand, which can be further increased when equipped with a battery. In countries where there is a shortage of electricity supply, this can help relieve the grid's pressure for supply. For the household in Lao PDR, a 6 kW solar PV system with a 12 kWh battery can supply around 98% of the family's annual electricity demand.

Figure 4-18. Share of Electricity Demand Met By Solar + Battery System



PV = photovoltaic; kWh = kilowatt-hour.

Source: Author's calculation.

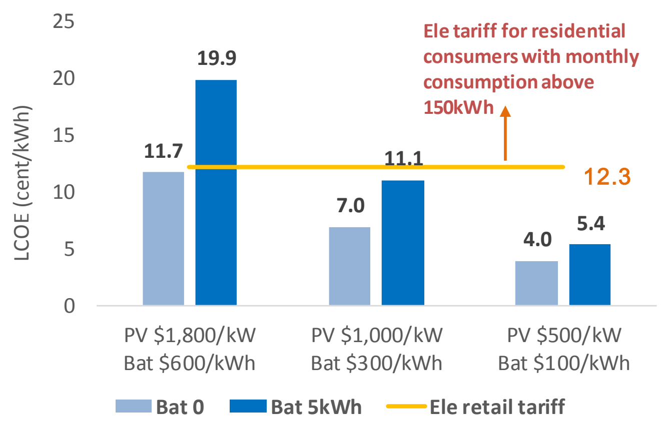
(2) Economics of energy storage for residential solar PV

The economics of solar PV + battery depends on the system's cost as well as on whether net metering is allowed and how that is compensated. From the solar PV installer's perspective, if the excess solar PV can be sold back to the grid at a higher price (such as the feed-in-tariff policy in Japan for residential solar PV), there is no need to install a battery. However, in this case, the total cost of power supply will increase, and the additional cost will be shouldered by customers with no solar PV installations.

Otherwise, if the solar PV installer is not allowed to feed back the excess solar PV to the grid, or if it is allowed but the fed-back electricity will not be compensated as much as the electricity tariff, the incentive to install a battery starts to grow.

In places where net metering is allowed but the excess solar PV electricity is not compensated, the incentive for battery installation depends on whether the solar PV + battery could produce electricity much cheaper than the price of electricity from the grid. For example, in the case of Lao PDR, at current cost of solar PV and battery, electricity produced by a system consisting of a 4 kW solar PV and 5 kWh battery system is much higher than the electricity tariff. If the costs can be reduced to US$1,000/kW for solar PV and US$300/kWh for the battery, the system starts to be competitive compared with that of grid's electricity. If the cost will be further reduced to US$500/kW for solar PV and US$100/kWh for battery, the solar PV + battery system could produce cheaper electricity (Figure 4-19).

Figure 4-19. Power Generation Cost Of Solar PV and Solar PV + Battery Under Various Cost Assumptions (Solar PV 4 kW, Battery 5 kWh)



PV = photovoltaic; kWh = kilowatt-hour; LCOE = levelised cost of electricity.

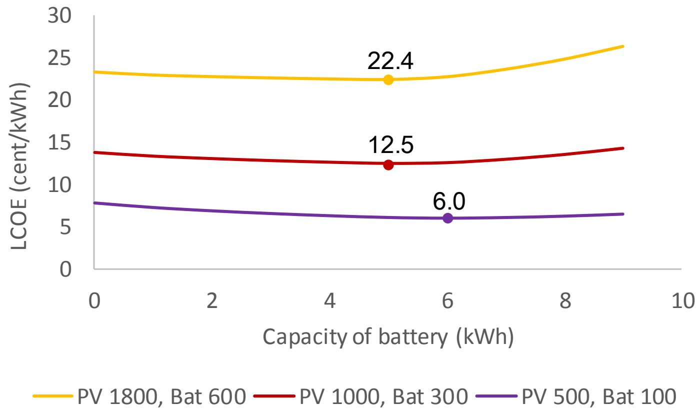
Source: Levelised cost of electricity (LCOE) results by author; information on electricity tariff from first workshop participant.

Figure 4-20 shows the power generation costs of the solar PV at various sizes of batteries for the same household and solar PV system (4 kW) but under a scenario where net metering is not allowed. If net metering is not allowed, excess solar PV will have to be curtailed, which means the improvement in self-consumption rate is the improvement in effective solar PV generation. The LCOE results suggest that although a battery system is an additional initial cost, the levelised power generation cost of the system is lower than that of a system without a battery because of the increase in effective power generation.

The self-consumption rate will improve at a lesser rate with every kWh of battery size increase (Figure 4-17). The same is true with the effective solar PV power generation. Therefore, there is an optimal combination of size of solar PV and of battery that can minimise the system's power generation cost. For a 4 kW solar PV system, the size of the battery that has the least generation cost is 5 kWh or 6 kWh, depending on the cost of both the solar PV and battery.

If net metering is not allowed, the power generation cost of residential solar PV + battery under current prices would be much higher than the electricity tariff in Lao PDR. When the system cost for solar PV and the battery changes to US$1,000/kW and US$300/kWh, respectively, the system starts to be competitive with the grid's electricity.

Figure 4-20. Power Generation Cost Of Solar PV + Battery When Net Metering Is Not Allowed (Solar PV 4kW)



LCOE = levelised cost of electricity; PV = photovoltaic.

Source: Authors' calculation.

4-6 Summary

One of the issues associated with high solar PV penetration is that the output of solar PV during its peak time could exceed the system's capacity to absorb. Excess solar PV generated that cannot be absorbed by the grid is usually curtailed. However, a high curtailment rate can ruin RE developers' revenue stream and discourage new investments on solar PV. Thus, one of energy storage technologies' applications is to avoid curtailment.

In this study's simulation, the required energy storage capacity to absorb the excess solar power under various assumed curtailment rates are calculated. For ASEAN countries covered in the simulation, a 1.1 kWh–1.9 kWh of energy storage capacity per kW of solar PV is required to avoid a 20% curtailment rate. To deal with a 40% curtailment rate, a 1.6 kWh–2.7 kWh energy storage per kW of solar PV would be needed. The result also shows that the required energy storage capacity to avoid curtailment of solar PV starts to increase sharply after the curtailment rate gets to a critical point.

The economics of energy storage in curtailment avoidance application is evaluated by comparing the LCOE without energy storage with LCOE of solar PV + energy storage. The comparison is done under three sets of cost assumptions for solar PV and energy storage.

Simulation results suggest that when curtailment rate is low, the installation of energy storage to avoid curtailment is more costly (than without energy storage) even in the lowest-cost case in this simulation. When the curtailment rate becomes higher, energy storage could be an economically viable measure to avoid curtailment. However, the viability is different from country to country depending on the system costs of solar PV and energy storage as well as the curtailment rate.

Another issue with solar PV is its intermittency, which can cause additional cost to grid operations. By pairing with energy storage systems, solar PV can the mitigated intermittency and reduce the negative impact on the grid stability. In the simulation, two cases on the solar PV and energy storage mix were discussed: daily capacity firming and electricity load following.

To achieve the specific output pattern for daily capacity firming, every kW of solar PV will require 1.8 kWh–2.5 kWh of energy storage. For load following, every 1 kW of solar PV would require 1.7 kWh–2.4 kWh of energy storage.

At current average prices of US$1,500/kW for solar PV and US$600/kWh for battery, the LCOE of the solar PV + battery system in most ASEAN countries is higher than US$0.26/kWh. However, such system can be competitive against diesel in some countries if both the solar PV cost and battery cost are reduced to US$1,000/kW and US$300/kWh. In this scenario, the system's LCOE becomes less than US$0.18/kWh.

Nowadays, solar PV's system cost can be as low as around US$1,000/kW in more mature markets such as Germany, China, and India.[5] Although the cost of batteries varies widely depending on the type, the Li-ion battery installation cost can go as low as US$200/kWh.[6]

If further cost reduction is realised (where the costs of solar PV and battery become US$500/kW and US$100/kWh, respectively), the solar PV + battery system can even compete with conventional power generation technologies in most ASEAN countries. According to IRENA and Fraunhofer ISE, the system cost of solar PV can be reduced to as low as US$630/kW till 2025[7] and US$320/kW[8] till 2050.[9]

The IRENA also forecasted that the installation cost of Li-ion battery could be reduced to US$77–US$215/kWh until 2030.[10] Given that most components of solar PV systems and batteries have become internationally circulated commodities, a medium- to long-term drop in the cost to US$500/kW for solar PV and US$100/kWh for battery is supposed to be within reach in ASEAN countries.

If PSH is available, the solar PV + PSH system could have lower LCOE and the same output pattern as that of solar PV + battery. However, when the battery cost is further reduced to US$100/kWh, it can compete with PSH in terms of the cost.

The use of batteries for residential solar PV systems was also discussed in the study, taking Lao PDR as an example. The electricity demand pattern is derived from surveys from households in a suburban area near Vientiane. The peak load is around 3 kW. In such a household, the self-consumption rate is around 50% for a 4 kW solar PV without any energy storage system. The self-consumption rate could be improved to 85% using a 5 kWh battery.

From the perspective of the PV installer, his economic incentives to install a battery depend not only on the system cost of the battery but also on the electricity tariff and the net metering policy. For example, if net metering is allowed and if the excess solar PV can be sold at a higher price, there will be no need to install a battery. However, if the excess solar power is compensated at a lower price or, worse, has no compensation at all, the incentive to install a battery storage

[5] IRENA (2018), 'Renewable Power Generation cost in 2017'.
[6] IRENA (2017), 'Electricity Storage and Renewables: Costs and Markets to 2030'.
[7] IRENA (2016), 'The Power to Change: Solar and Wind Cost Reduction Potential to 2025'.
[8] Converted from euro to US$ based on exchange rate of €1=US$1.14.
[9] Fraunhofer ISE (2015),'Current and Future Cost of Photovoltaics'. Presentation material at the IRENA Cost Competitiveness Workshop, Germany.
[10] IRENA (2017), 'Electricity Storage and Renewables: Costs and Markets to 2030'.

system comes from the reduction in the electricity bill by using self-generated electricity.

When the solar PV + battery system can produce electricity at a cost lower than the electricity tariff (which is the retail price of buying electricity from the grid), the end-users will prefer to use more self-generated electricity, thus giving them incentives to install batteries. The example of Lao PDR shows that, for the household with a 4 kW solar PV and 5 kWh battery (at current prices of US$1,800/kW for solar PV and US$600/kWh for the battery), electricity produced by the system is much higher than the electricity tariff. The system starts to become competitive with grid electricity when the costs of the solar PV and battery are reduced to US$1,000/kW and US$300/kWh, respectively.

If net metering is not allowed, the excess solar PV will have to be curtailed. For the same household with a 4 kW solar PV, the self-consumption rate is only around 50% when there is no battery. This means that about half of the power generated by the solar PV has to be thrown away (i.e. curtailed). In this case, the installation of a battery can help increase the effective solar power and, thus, lower the generation cost. The LCOE results show that there is an optimal size for solar PV and battery that will minimise the system's power generation cost. For a 4 kW solar PV system, the size of the battery that can bring the least generation cost is 5 kWh or 6 kWh, depending on the cost of the solar PV and battery.

Chapter 5

Policy Recommendations

This study shows that at the current price level of solar PV and battery in ASEAN countries, both the utility-scale solar PV (or large-scale solar PV plant) + battery system as well as residential solar PV + battery cannot compete with existing power supply options (such as conventional large-scale thermal power or residential electricity tariff). However, if the price of solar PV and battery decreases to the international best-price level in the future, the solar PV + battery system could compete with major conventional thermal power plants and bring benefits to residential customers as well.

Utility-scale solar PV + Battery

The solar PV's impact on the grid depends on the penetration rate of solar PV and the flexibility of the grid. When the penetration rate of solar PV is still low, its intermittency can be absorbed by the existing grid flexibility resources, such as ramping capability of the gas-fired power plants, interconnected transmission lines, and curtailment. Since these measures usually do not require additional investment, the cost is low. Therefore, in the short term, since the presence of solar PV in the grid is expected to remain low in most ASEAN countries, existing low-cost grid flexibility measures should be preferred.

However, **utility-scale solar PV + battery system can become a cost effective and clean substitute to diesel as a power supply to small and isolated systems** such as remote islands. In such places, the demand is small and the flexibility measure is few, which leaves energy storage as one of the limited options for balancing solar PV intermittency. In ASEAN countries, most of the remote islands rely on diesel for their power supply. Because of the high logistics cost of bringing diesel to the island, the cost of power supply is usually high and the system is constantly exposed to fuel price fluctuations.

Simulation results of this study indicate that, at their present prices (solar PV: US$1,500/kW, battery: US$600/kWh), power generation cost of solar PV + battery is still expensive (around

US$0.24–US$0.30/kWh) compare to diesel. However, the power generation cost of solar PV + battery will be lower than that of diesel generators when there are slight cost reductions (for example, solar PV to drop to US$1,000/kW and battery, to US$300/kWh). This is, in fact, already being achieved in nations outside of the ASEAN. In the short term, solar PV + battery can become a viable alternative to diesel as power source in isolated villages or remote islands once solar PV + battery costs reach the international best-practice level. However, it should also be made clear that since the battery is not suitable for inter-seasonal or seasonal energy storage, solar PV+ battery alone is not sufficient to provide 7/24 stable power supply.

Supporting policies are needed to further bring down solar PV + battery's power generation costs and make such system competitive when compared with conventional thermal power technologies. Simulation results show that if further solar PV and battery cost are reduced to US$500/kW (for solar PV) and US$100/kWh (for battery), the solar PV + battery system compete with conventional thermal power generation technologies (such as coal-fired or gas-fired thermal power) in ASEAN countries.

Although the cost reduction is contributed largely by the cost reduction and efficiency improvement in equipment (solar panel, inverter, Li-ion battery, etc.), it is also influenced by many other factors such as construction cost, logistics cost, financing cost, and land use cost. Policies such as on technical training of solar PV and battery project managers and installation contractors, low interest loan or loan guarantee, permits to use public land at low cost, and supports on land use negotiations, can help bring down the solar PV + battery system's generation cost.

Rooftop Solar PV + Battery

If residential solar PV + battery system can supply electricity at cost lower than the grid's electricity tariff, the former's penetration rate is expected to grow rapidly. At the same time, regulations and mechanisms that encourage self-consumption of the residential solar PV power generation are important in maintaining the grid's stability and in ensuring fairness amongst customers.

Table 5–1. Essentials of Policy Design for Utility-Scale Solar PV + Battery

	Application	Flexibility measures
Short term	Remote/isolated area application to partly replace diesel generator.	Explore existing low-cost measures -– e.g., ramping capability of gas-fired power plants, interconnection of transmission lines, and curtailment.
Long term	Larger application to replace conventional thermal power.	Support solar PV + battery system's cost reduction

Note: The table is indicative. Policy designs generally differ by country.

Source: Authors.

In places such as Australia and Hawaii, where residential solar PV is starting to become competitive vis-à-vis the grid's electricity, the issue of how to handle the excess solar power feeding back into the grid is looming large. In such places, policy priority is shifting from encouraging installation of solar PV to encouraging self-consumption of solar PV. In this case, battery is the most effective option for improving the self-consumption rate of residential solar PV.

Although the penetration rate of residential solar PV in ASEAN countries is still low, the continuing cost reduction in residential solar PV systems (even if equipped with batteries) could become increasingly competitive with the electricity supplied from the grid. The case study on residential solar PV in Lao PDR shows that, for the typical household in a suburban area close to Vientiane, the power supply cost of a 4 kW solar PV with 5 kWh battery system could proximate the grid electricity tariff if the costs of solar PV and battery are reduced to US$1,000/kW and US$300/kWh, respectively.

On the other hand, the economics of residential solar PV + battery is highly dependent on whether net metering is allowed and how the excess power fed back to the grid is compensated. From the end-user's perspective, if net metering is not allowed, all the cost of solar PV is borne by the installer; hence, the customers will have little incentive to install solar PV system when the cost is high. If net metering is allowed and the fed-back power to the grid is compensated at a high price, part of the cost of solar PV system can be recovered by selling electricity to the grid, and the incentive for solar PV installation will be higher. In this case, when the excess power can be sold to the grid at a higher price, the need for an energy storage system, i.e. batteries, is low.

However, from the perspective of the whole grid, net metering is supposed to bring two negative effects. First, an increase in fed-back power from residential solar PV systems will increase the fluctuations in the distribution network. Second, compensating the excess residential solar PV at higher price means that it increases the amount shouldered by all the customers, including households that do not have solar PV installed in their homes.

Therefore, it is when residential solar PV is still scarce that both net metering and compensation for the fed-back power can help encourage the installation of more solar PV system. When the penetration rate starts to rise, policies such as limiting the fed-back power to the grid or lowering compensation to the residential solar power sold to the grid, imposing flexible electricity tariff mechanisms, and rolling out smart meters, can help harmonise residential solar PV, battery, and grid operations. Detailed policy designs could vary from country to country, or even from service area to service area, depending on their social-economic conditions and electricity market structure.

Table 5–2. Essentials of Policy Design for Rooftop Solar PV

	Priority of policy	Policy instrument	
		Net metering of excess solar power	Compensation for solar power fed back to the grid
Pre-mature market	Increase solar PV capacity	Allow	High
	↓	↓	↓
Mature market	Increase self-consumption of solar power (storage capacity)	Restrict	Low

PV = photovoltaics.

Note: The table is indicative. Detail design of policy will differ by country.

Source: Authors.

Long-term Comprehensive Strategy

In the long term, an energy storage deployment strategy should be an integral part of a country's long-term power generation development plan. The need for energy storage is determined by the penetration level of variable renewable energy as well as the potential and cost of other grid flexibility measures.

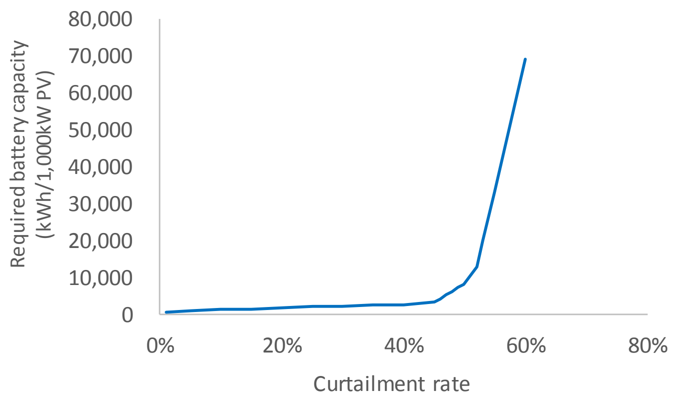
In a larger system, there is higher grid flexibility to accommodate variable renewables, but when all the low-cost grid flexibility potential is exhausted, energy storage is a natural choice to maintain the grid's stability. Amongst the major energy storage options, pumped storage hydropower and battery systems are promising technologies. Although the pumped storage hydropower, as a matured technology, is less expensive in terms of cost per unit capacity, it requires huge land acquisition and longer construction time. On the other hand, batteries, although currently still expensive, is more flexible and can be a practical solution for variable renewable technologies' grid integration. Since there are a wide variety of batteries, each exhibiting distinctive characteristics and trends in terms of cost reduction, construction lead time, etc., a comprehensive energy storage strategy that considers a country's long-term energy plan can help policymakers develop well targeted and effective supporting policies.

Annex 1. Results by Country

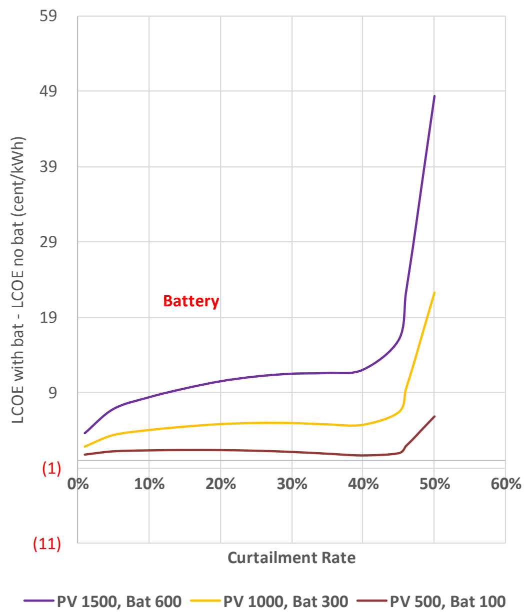
Cambodia

Observed electricity load curve data of January (2018) was provided by the participant of the first workshop meeting. Load curve data from February to December were filled per week by using the weekly average value calculated from the observed data.

(1) Required battery capacity per 1,000 kW of PV



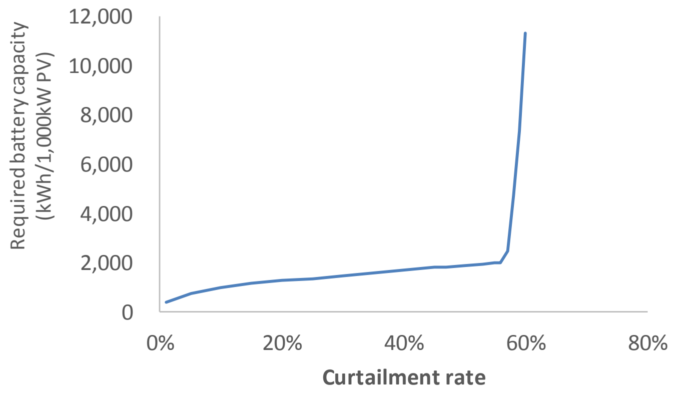
(2) Economics of energy storage for curtailment avoidance



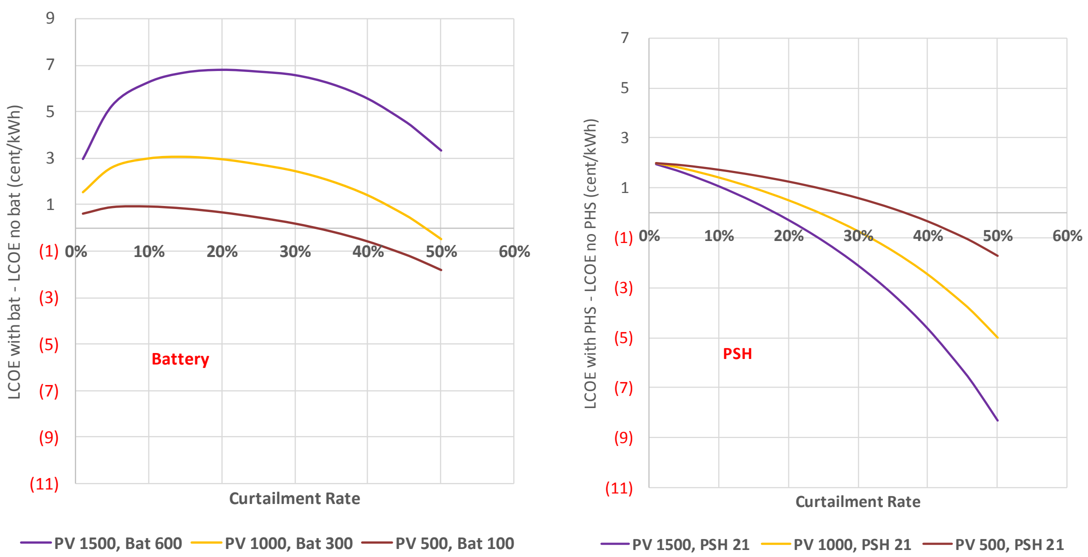
Indonesia Java–Bali

Two patterns of daily load curve, differentiated by season (dry/rainy), were applied to the whole year. The data is derived from previous ERIA studies.

(1) Required battery capacity per 1,000 kW of PV

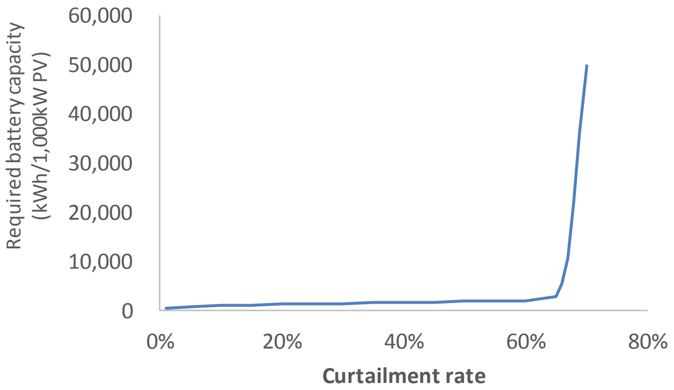


(2) Economics of energy storage for curtailment avoidance

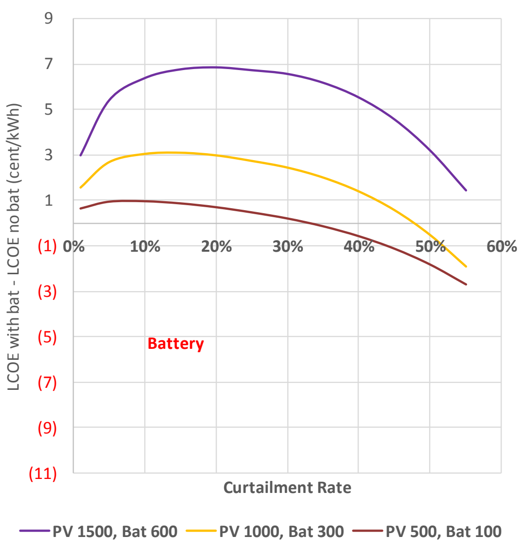


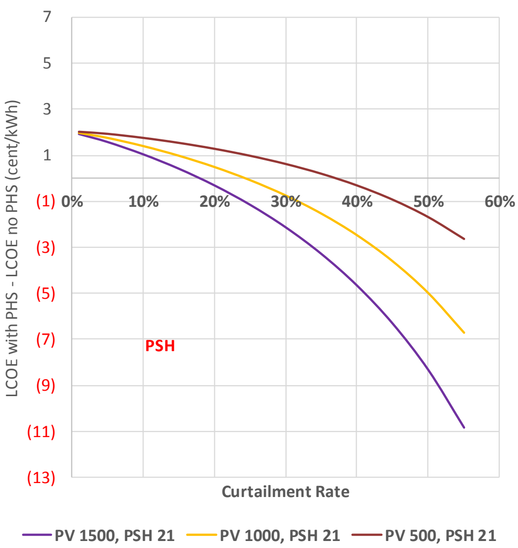
Indonesia Sumba Island

(1) Required battery capacity per 1,000 kW of PV



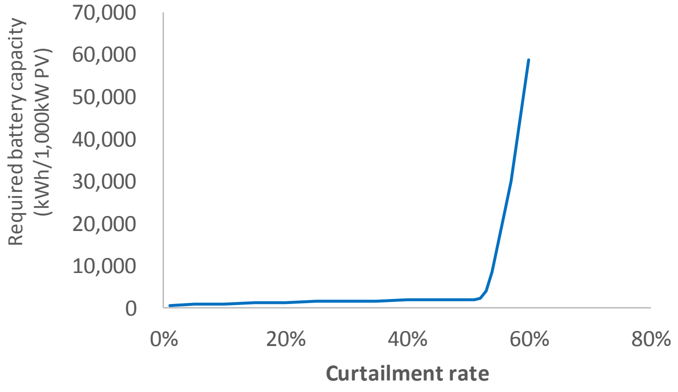
(2) Economics of energy storage for curtailment avoidance



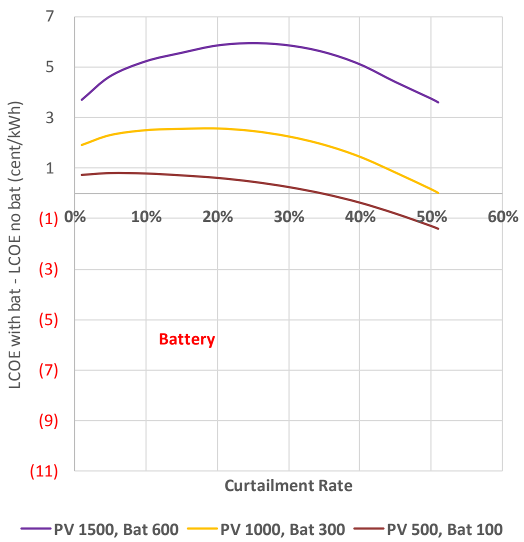


Lao PDR

(1) Required battery capacity per 1,000 kW of PV

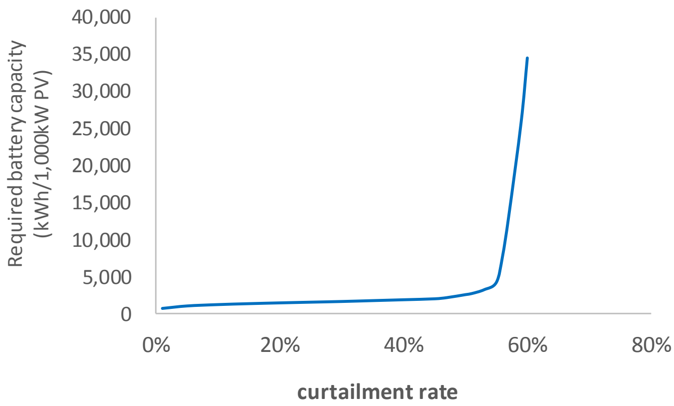


(2) Economics of energy storage for curtailment avoidance

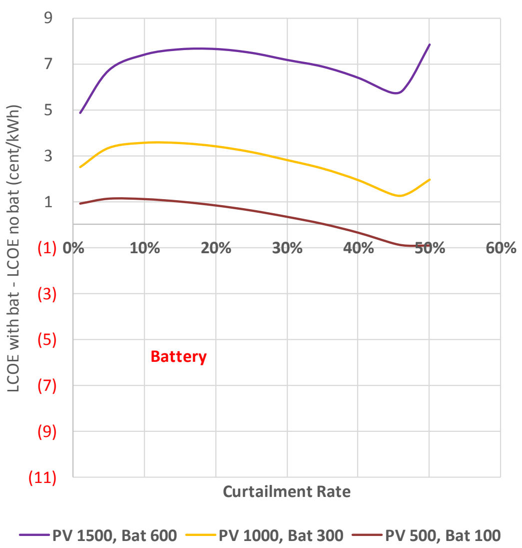


Malaysia

(1) Required battery capacity per 1,000 kW of PV

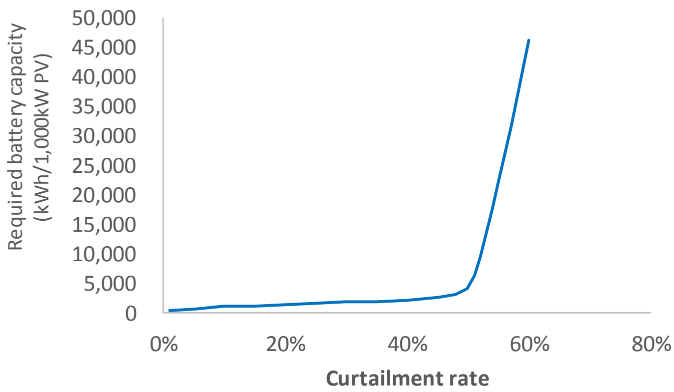


(2) Economics of energy storage for curtailment avoidance

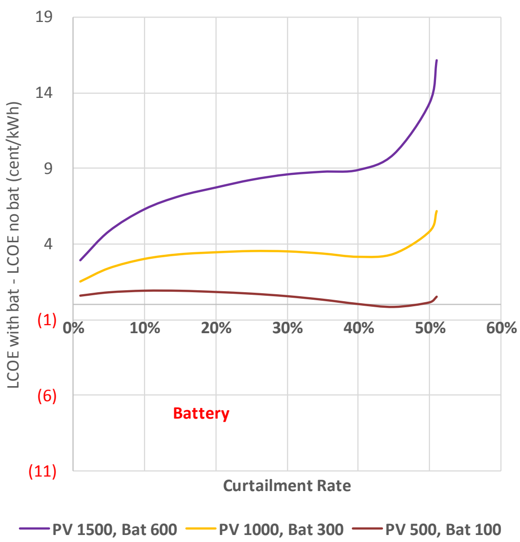


Myanmar

(1) Required battery capacity per 1,000 kW of PV

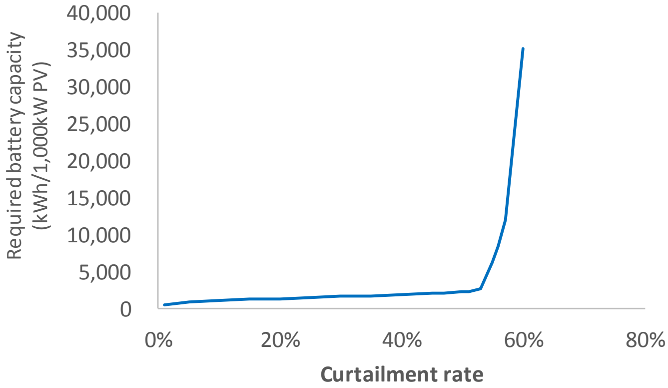


(2) Economics of energy storage for curtailment avoidance

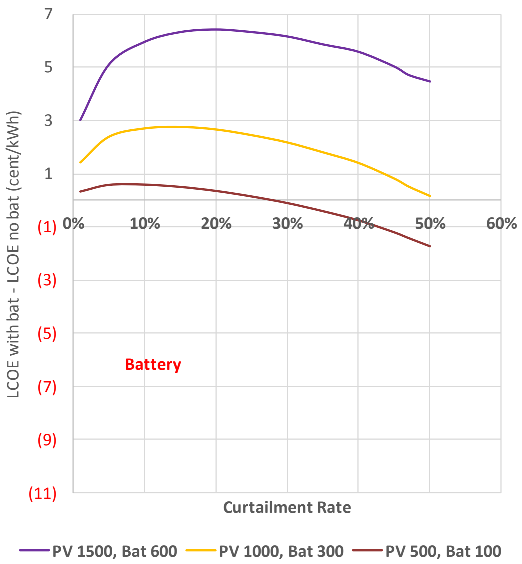


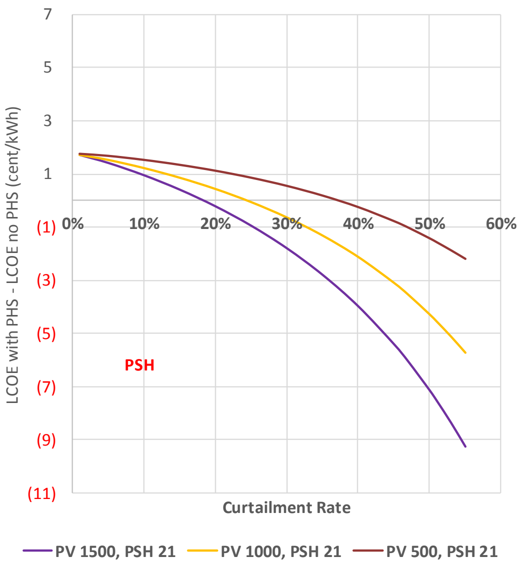
Thailand

(1) Required battery capacity per 1,000 kW of PV



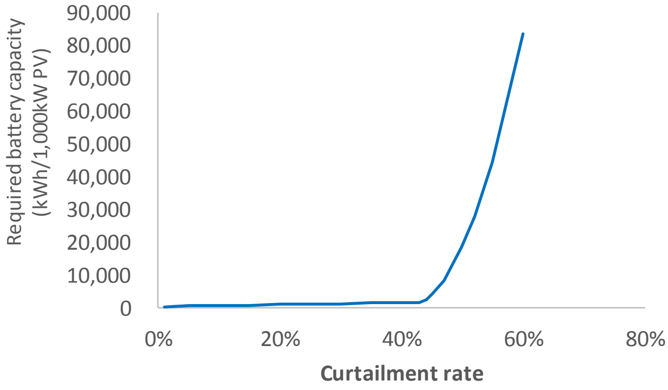
(2) Economics of energy storage for curtailment avoidance



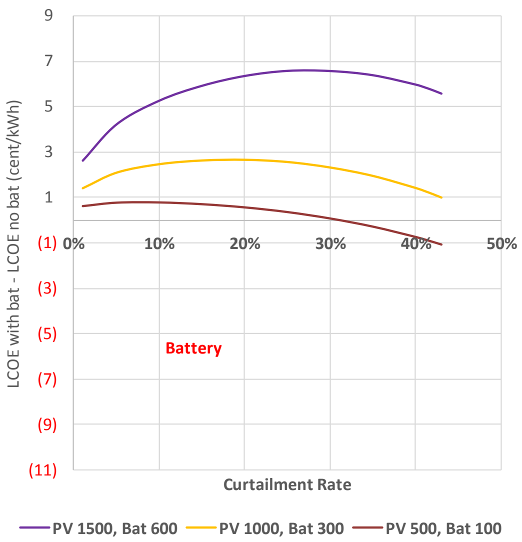


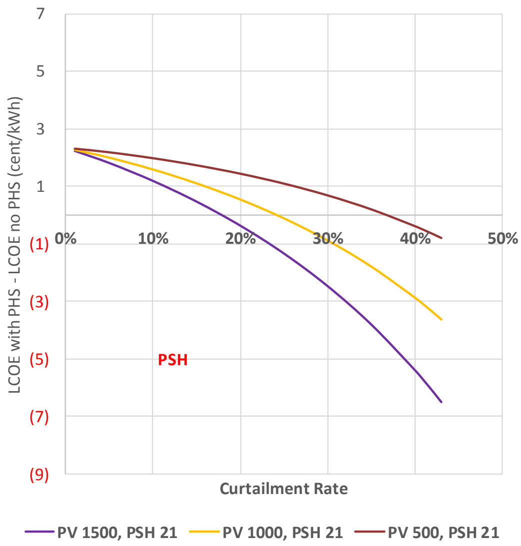
Viet Nam

(1) Required battery capacity per 1,000 kW of PV



(2) Economics of energy storage for curtailment avoidance





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