Centre for Governance and Sustainability
NUS Business School

RENEWABLE ENERGY AND STORAGE SOLUTION LANDSCAPE STUDY IN APAC

STRATEGIES FOR RENEWABLE ENERGY INTEGRATION & STORAGE SOLUTIONS IN SINGAPORE

Lawrence LOH; JIANG Peiyi; LIN Xuanchang; Nabil KAMALUDEEN; SUN Cuimin; WANG Yuxi

November 2023

Table of Contents

List of Figures

List of Tables

1. Executive Summary

1.1. Background

As the world grapples with climate change, there is a strong call for renewable energy to replace fossil fuels for our energy needs. According to the International Energy Agency (IEA), the growth in renewable energy was accelerated by the shock in global energy markets in 2022. Renewable energy is expected to be the largest source of energy generation by 2027 (Nadiq, 2022). In addition to the need to ramp up production for renewable energy, there is also a need to provide an infrastructure and storage hub for renewable energy.

Singapore, with the aspiration to become a pivotal energy hub in the Asia-Pacific (APAC) region, has allocated substantial funding and resources to develop a comprehensive energy ecosystem, with a particular emphasis on expanding its solar capacity. As Singapore strives toward its ambitious target of achieving net-zero emissions by 2050, it must address a range of challenges spanning geographical, regulatory, implementation, and technical aspects.

1.2. Research Objectives

In this study, our team aims to examine Singapore's current status in the realm of renewable energy, with a specific emphasis on solar energy and Energy Storage Systems (ESS). Through our research, we seek to pinpoint the significant challenges Singapore faces and offer a comprehensive strategic roadmap, to guide the nation toward a more sustainable future.

1.3. Research Methodology

Our study features both primary and secondary research. Primary research involves surveys and interviews with industry professionals and secondary research encompasses a thorough literature review of policy papers, research papers, news articles, consultant reports etc., of 12 countries within the Asia-Pacific (APAC) region. Through this comprehensive analysis of their renewable energy landscapes, regulatory developments, challenges, and ESS solutions, we aim to draw parallels between Singapore and these countries, identifying best practices that Singapore could potentially adopt.

1.4. Recommendations

Our team has analysed three potential renewable energy growth scenarios: slower growth than projected, expected growth, and growth surpassing expectations. We have developed tailored recommendations for each scenario to optimise outcomes.

In the event that renewable energy growth is lacklustre, Singapore can explore financial incentives to boost solar installations on privately-owned buildings. Given the land constraint, floating solar in remote sea areas could also be a potential solution. In this scenario, the need for ESS is less pertinent. Should renewable energy growth continue as forecasted, ESS would be necessary to manage the intermittency of energy generated by renewables. Hence, second-life Electric Vehicle (EV) batteries could be repurposed and incorporated in solar rooftop PVs. To further facilitate an efficient usage and distribution of renewable energy, Singapore can look into implementing Virtual Power Plants (VPPs). In the last scenario where renewable energy growth exceeds forecasts, smart metering is a possible solution to turn consumers into prosumers, enhancing energy efficiency.

2. Introduction

Climate change and global warming pose significant threats to humanity, demanding urgent action to mitigate their detrimental effects. This imperative for change is fuelling global transformations, particularly in sectors responsible for the highest carbon emissions. At the forefront of this global movement are pivotal agreements like the Paris Agreement and the United Nations 2030 Sustainable Development Agenda. These agreements share a common objective - to limit the global temperature increase to 1.5 degrees celsius above pre-industrial levels by focusing on substantial reductions in greenhouse gas emissions. These international efforts are dedicated to forging a more sustainable future for all.

In alignment with this global momentum to address the impending challenges of climate change, Singapore has embarked on an ambitious trajectory. Singapore has set ambitious targets and made substantial investments in renewable energy, with a particular emphasis on solar power. However, as Singapore ramps up its solar energy capacity, it confronts formidable challenges rooted in its unique geographical constraints. These challenges amplify concerns regarding the cost-effectiveness and broader commercial viability of renewable energy projects within the nation.

This study seeks to provide a comprehensive evaluation of Singapore's current state of renewable energy and propose potential solutions to address the critical issues it faces. Through meticulous analysis and research, we aim to offer valuable insights and strategies that can contribute to Singapore's sustainable energy transformation.

3. Research Methodology

Primary research will involve the implementation of surveys and in-depth interviews conducted with four industry experts, selected for their backgrounds in either operational or investment roles. These experts represent prominent organisations, including Gurīn Energy, Enedis, Total Energy, Macquarie Capital and Singapore Power. The survey questions are meticulously designed to facilitate a nuanced understanding of the challenges confronting Singapore and to evaluate the feasibility of our proposed recommendations.

The secondary research component of our methodology consists of an exhaustive literature review conducted across 12 countries situated within the Asia-Pacific (APAC) region. These countries encompass Australia, China, India, Indonesia, Japan, Malaysia, New Zealand, the Philippines, South Korea, Singapore, Thailand, and Vietnam. This comprehensive analysis delves into the respective renewable energy landscapes, regulatory frameworks, challenges, and prevailing energy storage solutions (ESS). The research's overarching aim is to discern parallels between Singapore and these nations. Employing a comparative framework, we endeavour to identify and recommend best practices that Singapore could potentially assimilate into its renewable energy strategy.

4. Overview of Renewable Energy in Singapore

4.1. Current State of Singapore's Renewable Energy

4.1.1 Singapore's Current Energy Mix

Although Singapore only contributes to 0.1% of global carbon emissions (Prime Minister's Office Singapore, 2022), Singapore is no outlier to this global aspiration, and is making significant progress towards the goal of carbon emission reduction. Furthermore, Singapore has pledged to achieve net zero emissions by 2050. With the energy sector accounting for 40% of Singapore's total emissions (EMA, 2023), Singapore has made this sector a focus for its decarbonisation efforts.

The majority of emissions from the power sector in Singapore stems from the production of energy by burning Liquified Natural Gas (LNG). LNG is regarded as a cleaner energy source compared to oil and coal as it is more efficient. It produces 30% less carbon dioxide than oil and 40% less than coal per unit of energy generated (National Grid, 2023). Hence from 2000-2022, the percentage of energy generated from LNG rose from 19% to 95% in Singapore. Coal and oil currently make up 1.2% and 1% of Singapore's energy generation.

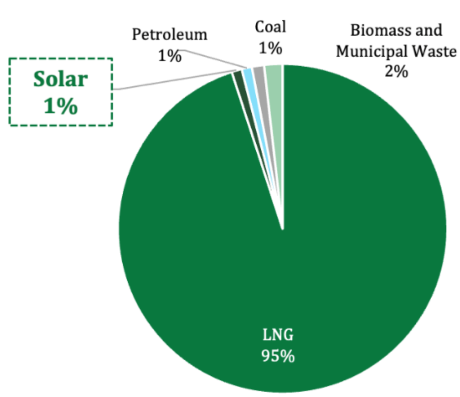

Figure 4.1.1: Energy Mix in Singapore (EMA, 2023)

Of the remaining 2.8% of energy generated, 1% is by solar and 1.8% is by biomass and municipal waste. Although LNG is considered to be a cleaner source of energy as compared to oil and coal, production of energy from LNG still produces carbon dioxide. As part of Singapore's plans to achieve net zero, Singapore plans to increase the share of renewable energy in its total energy production and reduce the share of energy generated by LNG. More specifically, Singapore plans to produce 2.0 gigawatt-peak (GWp) of solar energy by 2030, which would make up 3% of total energy demand. This would be enough to power 350,000 households in Singapore annually (Tan, 2020).

4.1.2 Singapore's Energy Framework

Singapore adopts two frameworks to guide its policy and decision making when it comes to energy. The first framework is the Energy Trilemma. The Energy Trilemma asks the question of how Singapore can obtain energy which is 1. secure and reliable 2. affordable 3. environmentally sustainable. A single source of energy would not be able to fulfil all three criteria and thus Singapore has a mix of energy sources which are highlighted in the Four Switches Framework.

The Four Switches refer to the four main sources of energy which Singapore plans to utilise to ensure that the energy mix fulfils the Energy Trilemma. The four switches include 1. Natural Gas 2. Solar energy 3. Regional power grids 4. Emerging low-carbon alternatives. Combined, these two frameworks help Singapore set its goals and guide policy decisions when it comes to the energy mix.

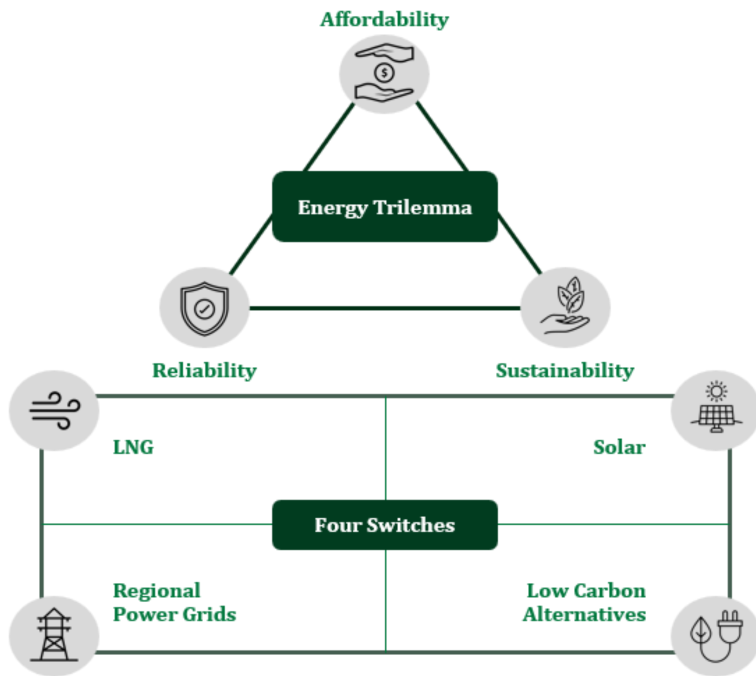

Figure 4.1.2: Energy Trilemma and Four Switch Framework (Ministry of Trade and Industry, 2023)

1. **Natural Gas** — LNG, being the cleanest form of fossil fuel, will continue to be the main source of fossil fuel for Singapore in the foreseeable future while Singapore looks to scale up the other 3 switches.
2. **Solar** — Solar is Singapore's most viable source of renewable energy given the constraints. Moreover, solar is the cheapest source of renewable energy (IRENA, 2022).
3. **Regional Power Grids** — Singapore recognises that its limited land size is a major constraining factor in the scale up of solar PV. To continue its trajectory to net-zero by 2050, Singapore has signed multiple agreements with neighbouring countries to import low-carbon sources of electricity and plans to import 30% of its total electricity demand from neighbouring countries by 2035.
4. **Low-Carbon Alternatives** — Singapore continues to explore other sources of renewable energy generation such as geothermal energy and hydrogen cells as a means to store energy.

4.1.3 Structure of the Energy Market in Singapore

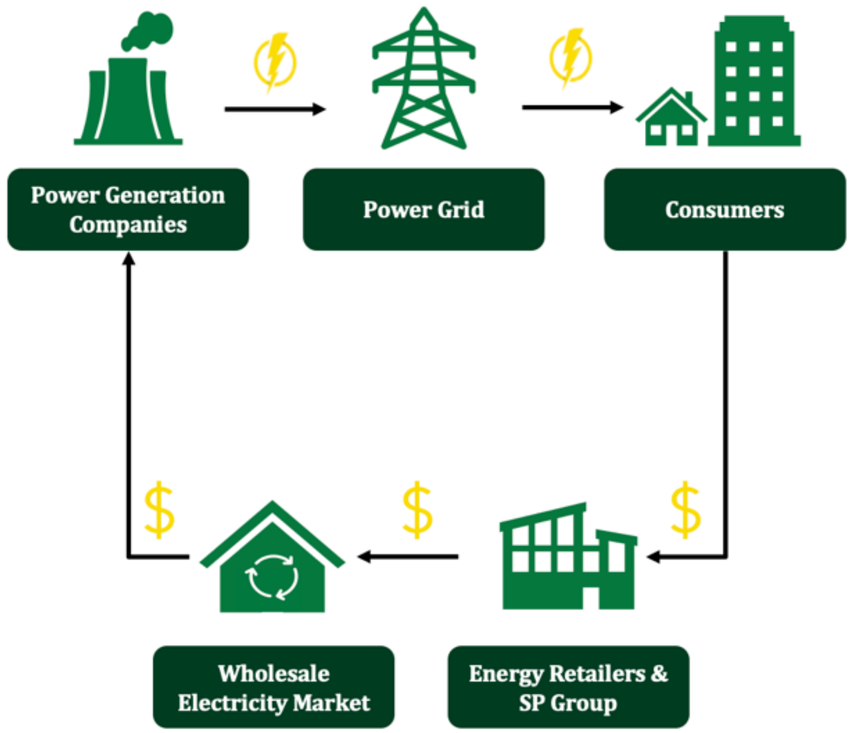

Figure 4.1.3: Flow of Electricity and Money in Singapore (EMA, 2023)

Stakeholders	Examples	Role / Details
Power Generation Companies	• Tuas Power Generation, Senoko Energy, Keppel Merlimau Cogen etc.	• Power generation companies compete to generate and sell electricity in the wholesale electricity market every half-hour.
Energy Market Authority	-	• Statutory board under the Ministry of Trade and Industry • Oversees Singapore's electricity and gas sectors
Energy Market Company	-	• Operates and administers the wholesale electricity market (WEM) owned by the Singapore Exchange (SGX)
SP Group	-	• Operates and maintains the power grid • Delivers electricity island wide and provides services i.e., metre reading, data managing and facilitating customer transfers between retailers
Electricity Retailers	• Seraya Energy, Keppel Electric, Pacific Light Energy, Sembcorp Power etc.	• Electricity retailers buy electricity in bulk from the WEM and compete to sell electricity to consumers
Consumers	• Households, buildings, factories etc.	• 1) Contestable consumers purchase power from retailers of choice at the market rate • 2) Non contestable consumers purchase power from SP Group at a fixed regulated tariff

Table 4.1.1: Key Stakeholders in Singapore's Energy Market

4.1.4 Power Grid in Singapore

SP Group owns and operates Singapore's power grid and electricity network. This includes the transmission and distribution of electricity and the power lines and substations needed. Singapore's electricity grid consists of more than 20,000 km of underground cables interconnecting more than 9,800 substations in the transmission and distribution networks (National Climate Change Secretariat, 2011). The power grid in Singapore is one of the most reliable and robust in the world with intelligent components installed in numerous segments of the generation and transmission network (NTU & SPECS, 2019). Based on a benchmarking report in 2020, customers in Singapore experienced an average of 0.15 minute of electricity interruption (SP Group, 2023). SP Group is fully owned by Singapore's investment fund, Temasek which is fully owned by the Singapore Government.

4.1.5 Policies to Incentivise Renewable Energy Investment in Singapore

According to world bank, Singapore has the least developed incentive mechanism and regulatory support systems for renewable energy amongst ASEAN countries (ASEAN Centre for Energy, 2020)

There are no clear subsidies or incentives given by the government or the EMA for renewable energy projects such as solar PV installation. Moreover, unlike many other countries, Singapore does not have Feed-in Tariffs (FiTs) for solar energy. FiTs refer to an additional price that a power producer receives for supplying renewable energy to the grid. FiTs are viewed by the government to be an inefficient way of scaling up solar PVs in Singapore as it distorts the market and increases costs for consumers (EMA, 2023). Furthermore, the EMA believes in pricing energy correctly so that it sends the right signal to consumers and producers.

Instead of providing incentives or subsidies to investors and projects, Singapore chooses to work closely with the industry and invest heavily in R&D with the hopes that the technological and economical aspect of renewable energy becomes commercially viable and thus making renewable energy adoption a natural consequence. This is as opposed to providing subsidies and financial incentives which obscures the true cost and leads to suboptimal outcomes.

4.2. Solar Energy Trend in Singapore

The growth of installed solar capacity in Singapore has been facilitated by falling costs of PV. Between 2010 to 2018, the cost of generating 1Wp has fallen by more than 80% and is expected to continue falling (NUS & SERIS, 2020), further assisting the growth of solar PV in Singapore. Although solar is the most viable renewable energy in Singapore, it is not land efficient. Therefore, its scale-up is fundamentally limited by Singapore's land constraints (National Climate Change Secretariat Singapore, 2022). A study conducted by Solar Energy Research Institute of Singapore (SERIS) estimated that the total usable area for solar PV deployment is 36.8 km^2. This area includes roof-tops, building facades, land, reservoirs for floating PV and infrastructure PV such as roads and canals. It is estimated that this would have the potential to generate up to 8.6 GWp of solar energy, meeting 10% of total energy demand in 2050.

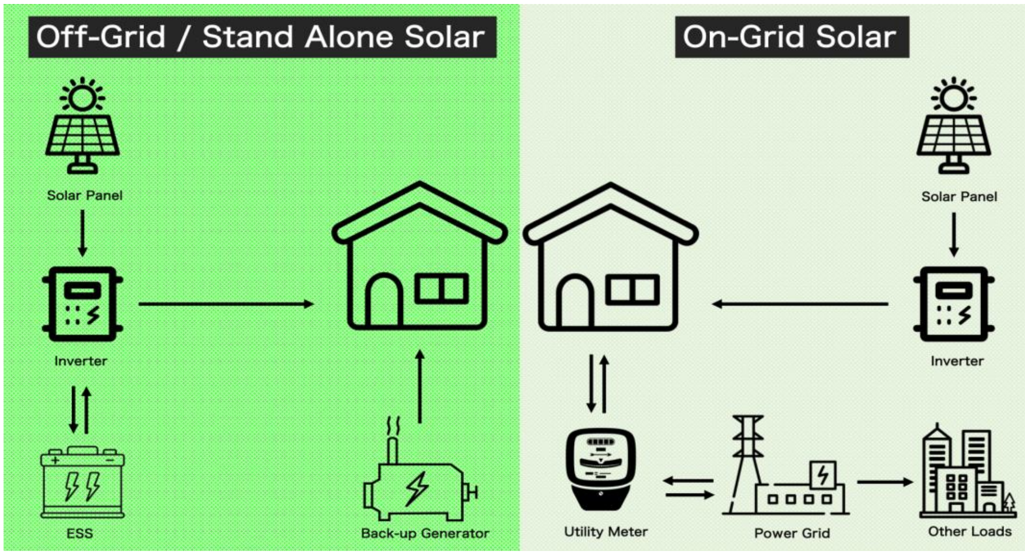

Figure 4.2.1: Difference Between Off-Grid and On-Grid Solar

An on-grid solar PV is one which is connected to the power grid and is able to supply the grid with excess solar energy. As such, on-grid solar PVs do not require an ESS to absorb excess energy generated. In the case where solar energy generation is not sufficient to meet the demands of the load, energy will be drawn from the grid to make up the excess demand. An off-grid solar PV is one which is not connected to the power grid and thus is not able to supply excess energy to the grid. An ESS is then required to absorb excess energy to be used at a later time.

In Singapore, most solar panels involve a grid-tied set up. The installation of solar panels for commercial, industrial or residential use is overseen by the EMA and requires approval by other regulators such as the Urban Redevelopment Agency (URA) and Singapore Civil Defence Force (SCDF). Given that most solar panels are grid tied, excess energy generated by solar is distributed to other loads efficiently, hence no wastage of energy occurs and ESS for capturing excess energy is not needed. Furthermore, ESS requires more initial and operating cost which may offset savings from drawing electricity from the grid.

4.3. Challenges of Renewable Energy Generation in Singapore

Singapore is at a disadvantage when it comes to renewable energy generation. With just 734 km^2 area of land, a high urban density, low wind speeds, flat land and a lack of geothermal energy, Singapore's ability to harness renewable energy such as wind, tidal, geothermal and hydro are all limited. Singapore's alternative-energy disadvantaged status is officially recognised by the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2018). Given these limitations, carbon reduction in Singapore is expected to be more difficult in Singapore than it is in other countries with more abundant natural resources. With these constraints, and with sunshine all year round, solar energy is viewed as the most viable source of renewable energy generation in Singapore and is one of the key switches in the Four Switch Framework. While Singapore is actively exploring alternative sources of renewable energy such as geothermal and hydrogen energy, currently, no energy is being produced from these sources.

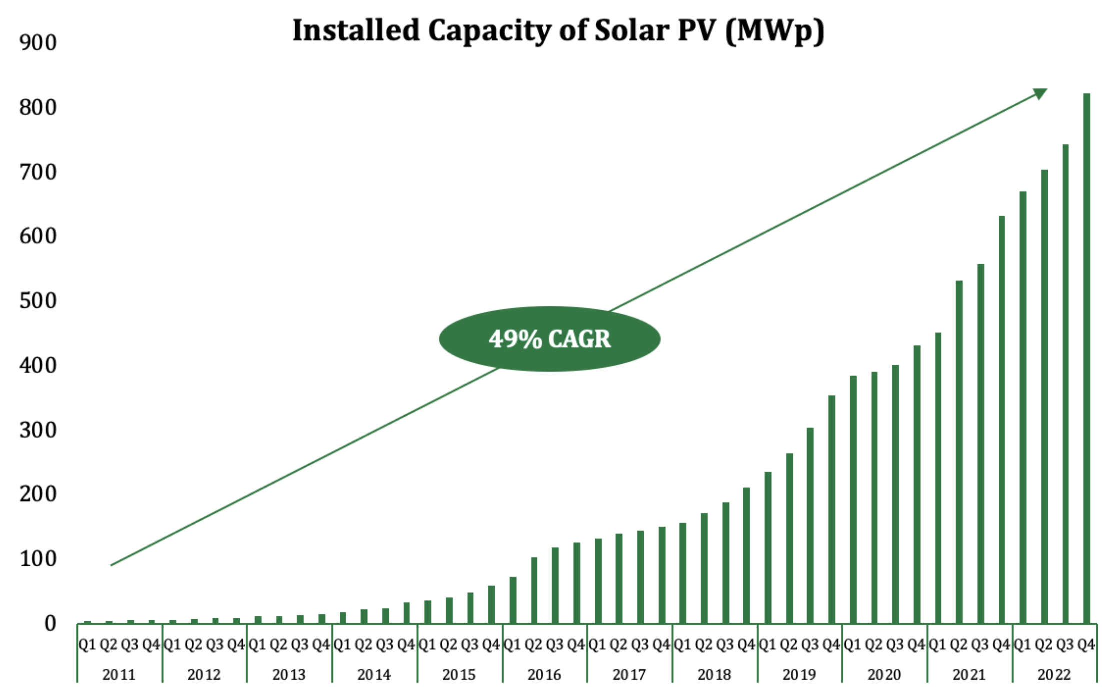

Figure 4.3.1: Growth of Installed Solar Capacity in Singapore (EMA, 2023)

Installed capacity for solar energy in Singapore has risen exponentially over the past 10 years. As of end 2022, Singapore's total installed capacity for solar energy stood at 820 MWp (EMA, 2023), just above the halfway mark of the 1.5 GWp target by 2025 and 40% of its 2.0 GWp goal by 2030. Despite the challenges, Singapore has become one of the most solar-dense cities in the world, having multiplied its solar capacity by more than seven times since 2015 (Economic Development Board, 2022)

4.4. Energy Storage Systems (ESS) in Singapore

Solar energy is categorised as an intermittent generation source (IGS). Solar energy relies on sunlight for generation, meaning that no solar energy production would occur at night and during times of cloud cover. This is unlike conventional sources of energy generation such as the burning of oil, gas and coal which can be called upon to increase energy output at any given time. Additionally, if solar energy is not consumed immediately, then the excess energy goes unused and is essentially wasted. To address solar intermittency, therein lies the need for ESS to capture excess solar energy for storage and usage at a later time. Due to the low amounts of solar energy produced and the high energy demand in Singapore, virtually no solar energy is currently wasted. However, with the increase of solar energy feeding the grid, the intermittent nature of solar could have a noticeable impact on grid reliability such as fluctuations in voltage and power. Thus, with the forecasted growth of solar energy generation in Singapore, ESS becomes more essential in managing the intermittency.

Besides helping to address solar intermittency, ESS brings further stability to the power grid. Other benefits include (EMA, 2023):

- Shifting of peak electricity load to off-peak periods, helping to manage electricity prices.
- Provides ancillary services to the market by regulating and reserving energy, contributing to grid stability and reliability.

- Swiftly responds to power fluctuations within the grid, ensuring a reliable and consistent energy supply.

There are four existing ESS projects in Singapore with a combined storage capacity of 296.9 MW.

Figure 4.4.1: Existing ESS Projects in Singapore

All four projects are collaborations between the EMA and a private company, with the cost of the project borne by both parties. The U.S. Energy Information Administration reports that battery storage costs fell 72% between 2015 and 2019 and is expected to continue declining (Sinclair Digital, 2023). This was primarily driven by an increase of EV adoption which led to the mass production of batteries, particularly lithium-ion batteries. Research from the IEA in 2017 showed that Lithium-ion batteries are the dominant technology for ESS given its costs, longevity and efficiency. This is also the primary reason that all four projects utilise lithium-ion batteries.

Despite significant cost reduction, at the moment, the cost of lithium-ion ESS is still relatively high when compared to other technologies, which makes commercial viability challenging (EMA, 2018). A separate study found that the average payback period for an ESS system that is involved in energy arbitrage - buying and absorbing energy when prices are low and selling and injecting energy into the grid when prices are high - in Singapore, is 20 years (Low, 2018). This excludes financing, operational and maintenance costs.

Thus, at the current time, subsidies and partnerships would be required in order to incentivise participation from the private sector when it comes to ESS.

5. Literature Review of Renewable Energy Landscape in APAC

5.1. Vietnam

5.1.1. Overview

As Vietnam pivots towards environmental sustainability, renewable energy has assumed a pivotal role within the nation's energy portfolio. The government of Vietnam aims to have biomass, solar, hydroelectric, and wind energy constitute 48% of the country's installed capacity by 2030, with a further target of increasing this to approximately 63% by 2050.

Solar power, due to its cost-effectiveness, reliability and sustainable nature has rapidly gained prominence in Vietnam's energy market (Rapid Transition Alliance, 2023). As of 2021, Vietnam has emerged as the ninth-largest economy in terms of solar capacity, boasting approximately 17.6 gigawatts (GW) (International Trade Administration, 2022).

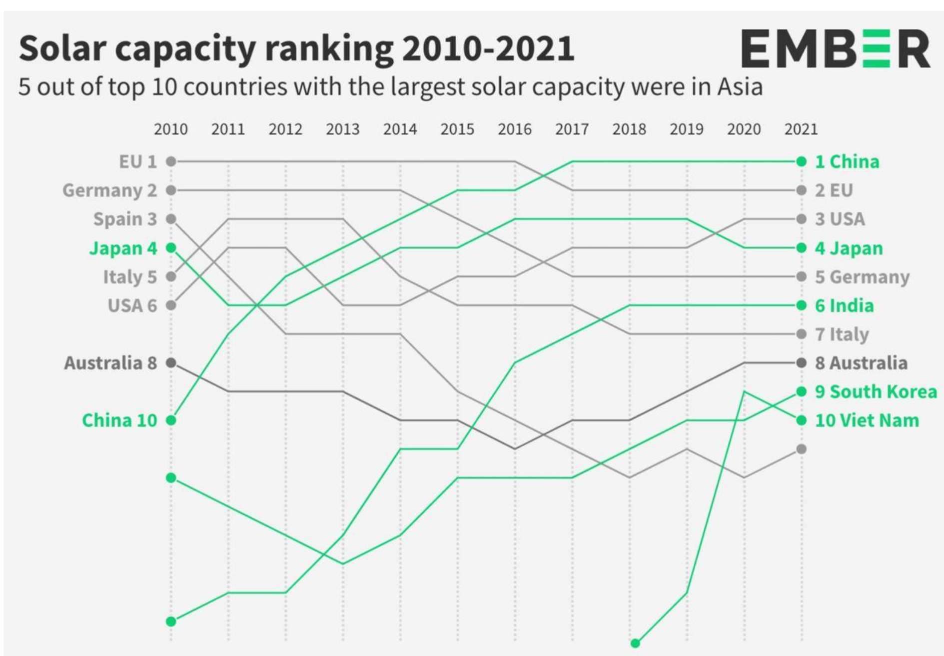

Figure 5.1.1: Vietnam's Solar Capacity Standing (IRENA, 2022)

In line with Vietnam's substantial commitment to expanding its solar capacities, the government has devised a plan for $135 billion investment into the power grid. This aims to enhance grid infrastructure, transmission lines, and substations to accommodate the increasing deployment of solar energy (Yen, 2023). In addition, the Vietnam Environment Protection Fund (VEPF) encourages renewable energy generation by providing subsidies for renewable electricity produced when production costs are more than the sale price (Mitchell & Seibert, 2019). Moreover, renewable energy development projects may qualify for corporate income tax and import tax benefits, including a 10% rate for 15 years, a 4-year corporate income tax exemption, and a 50% tax base reduction for the following 9 years (Bui & Vu, 2020).

Furthermore, the government has also taken steps to bolster residential solar capacity. Currently, there are 101,000 rooftop solar systems installed across resident, commercial and industrial buildings. As part of Vietnam's ambitious solar deployment goals, the government envisaged 50% of office and residential buildings to be self-sufficient in energy production by 2030, collectively providing a total development capacity of 2,600MW (Yen, 2023). Behind Vietnam's remarkable development in solar energy capability lies its natural advantages, including 1,600 to 2,700 sunlight hours and an average direct normal irradiance of 4-5 kWh per sqm per day (Das, 2018). These factors contribute to an estimated economic solar potential of 380GW (McKinsey, 2022).

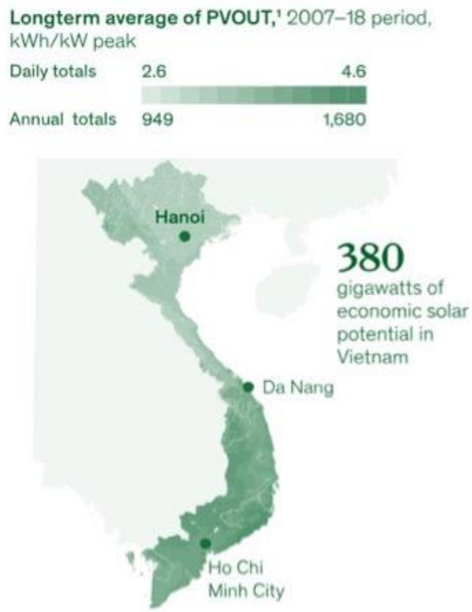

Figure 5.1.2: Vietnam's Economic Solar Potential (Mckinsey, 2022)

5.1.2. Policies and Regulatory Development

Vietnam adopts a top-down approach to energy market regulation, characterised by active participation of multiple government entities in the solar sector. Among these entities, the Ministry of Industry and Trade of Vietnam (MOIT), serves as the central regulator responsible for overseeing the power sector.

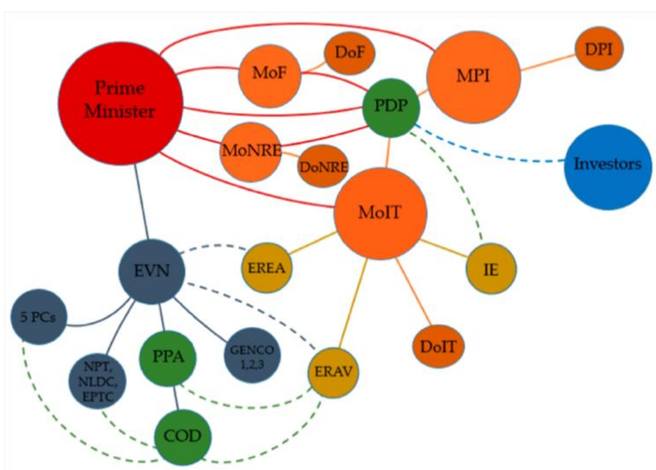

Figure 5.1.3: Actors in PDP, PPA and COD of Vietnam Solar Power (Riva Sanseverino et al. 2020)

One of the pivotal policies instituted by the Vietnamese government is Resolution 55, which stands as a comprehensive framework guiding the rapidly evolving energy sector. Beyond establishing specific quantitative targets for 2030 and 2045, Resolution 55 also encourages participation from the private sector to foster a diversified, and transparent energy market mechanism (Nguyen, 2022).

In the context of solar energy, Vietnam has introduced FIT2, a pricing system at $8.38 cents/kWh exclusively for rooftop solar projects. Ongoing discussions centre on the possibility of further discount or incentives to stimulate greater adoption of solar energy (Nguyen, 2022). Major discussion revolves around the potential implementation of a lower FIT3 at $5.2 to $5.8 US cents/kWh. Coupled with Vietnam's broader Solar Power Development Plan, the country aspires to generate as much as 18.9 GW of solar energy (Nguyen, 2022).

However, in the realm of energy storage solutions (ESS), while Vietnam's National Power Transmission Corporation has initiated investigation and piloted projects related to ESS, there has yet to be any regulatory development and supportive policies dedicated to the deployment of ESS.

5.1.2. Key Challenges

Vietnam faces significant challenges in the efficient allocation of its energy resources. Despite a substantial installed capacity, renewable energy output only accounts for 11.9% of the total mobilised output in the system in 2022. The discrepancy is primarily attributed to the delay in transitioning the pricing mechanism from FIT2 to potentially FIT3 (Trang, 2023). Even in cases where the new FIT prices have been issued, they have been subject to multiple cancellations before officially taking full effect, signalling a highly ineffective top-down management approach in Vietnam's energy market.

In addition, Vietnam's grid infrastructure has not kept pace with the increasing solar energy adoption. Currently, the oversupply of electricity poses a major threat to the security of national grid, especially at times of low economic activities when demand plummets (Nguyen, 2021). At noon time especially when solar energy production peaks but demand remains low, solar farms were compelled to cease operation. For instance, in 2020, energy regulators in Vietnam ordered a total reduction of 365 million kWh of solar power due to grid overload in central provinces like Ninh Thuan and Binh Thuan. As a result, solar energy development faced a bottleneck, rendering many solar projects financially unviable and leading to wasteful curtailment (Nguyen, 2021).

Furthermore, Vietnam's solar power development plan exhibits a narrow focus on areas with favourable solar potential (Riva, 2020). This could have a detrimental impact on the orientation of connecting solar power projects to the national power system in the short run and the possibility of sustainable and synchronised development across the country in the long term (Riva, 2020). Notably, there has been over-investment in areas such as Ninh Thuan, Binh Thuan and Khanh Hoa where grid-overload issues persist, significantly undermining efficiency of solar development projects and power transmission development.

5.1.3. Energy Storage Solutions

Vietnam's ESS is currently in its nascent stages, with no clear governance framework and regulatory development. Nevertheless, there have been notable strides in experimenting with ESS solutions. For instance, Vietnam's VinES Energy Solutions has partnered with renewable energy company SolarBK to promote the integration of battery storage with rooftop solar PV (Colthorpe, 2023). In addition, efforts have been dedicated to the first pilot deployment of large-scale BESS technology at the 50MWp Khanh Hoa solar PV plant (Colthorpe, 2023).

Despite these initiatives, challenges in ESS persist in Vietnam. This is primarily due to high cost of storage and innovation, especially for batteries with up to 4 hours of energy discharge per charge-discharge cycle. The high cost acts as a disincentive for investors, and government subsidies emerge as a crucial factor to propel further development in the field of ESS.

5.2. India

5.2.1. Overview

The deployment of renewable energy has emerged as a critical imperative for India, not only to enhance energy security, but also to spur economic development. Based on the International Energy Agency (IEA) (Jain, 2023), India's installed solar energy capacity will reach 71 GW in 2023, constituting 34% of India's total installed renewable capacity. Within this renewable energy mix, India's primary focus has been on solar power, with a total installed capacity of 62 GW by end 2022 (Government of India, 2023). Moving forward, the installed solar capacity is anticipated to continue expanding under the national solar mission to at least 450 GW by 2030, with further goals to raise solar power output to 1,689 GW by 2050 and an ambitious 5,630 GW by 2070 (IEA, 2021).

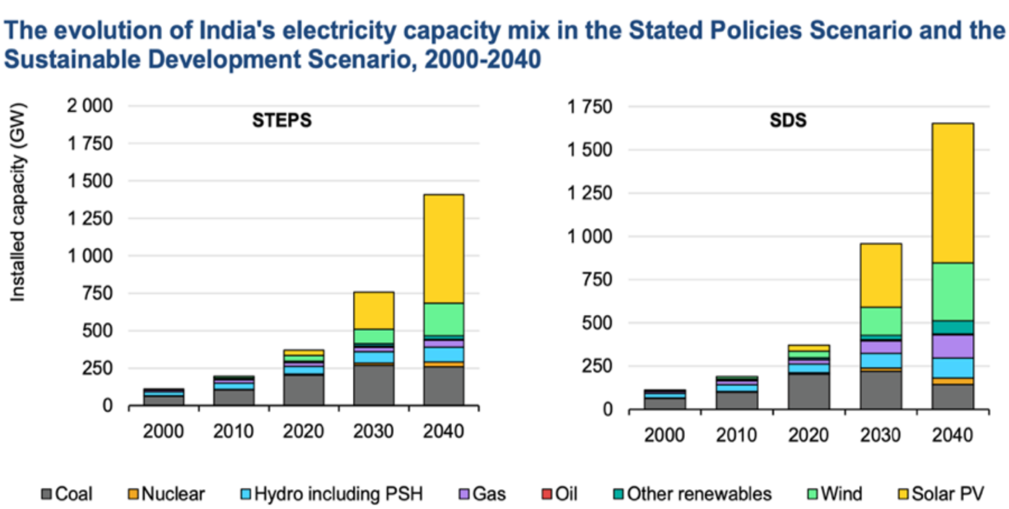

Figure 5.2.1: Evolution of India's Electricity Capacity in the Stated Policies Scenario (IEA, 2021)

One of the pivotal drivers behind the surge in solar energy in India has been the influx of foreign investments. In Q3 2023, India attracted $251 million foreign investments (Rakesh, 2023). A noteworthy example of such investment is the Pavagada Solar Park in Karnataka, which stands as the world's largest solar park with a total capacity of 2GW, backed by investors such as Softbank and Adani (Blackridge Research, 2023). Furthermore, to fully tap on the expanding renewable capacity, India has launched the green energy corridor project to optimise the transmission infrastructure for renewable energy (Jain, 2023).

Beyond conventional solar farms, India has been pioneering cutting-edge renewable technology. For instance, India houses the world's largest floating solar plant in Kerala leveraging its leading floating solar technologies, expected to generate 7.5 Lakh units of electricity annually (Shewali, 2017). In June 2023, India launched the Mission on Advanced and High-Impact Research, which aimed to facilitate domestic research, development and demonstration of the latest and emerging technologies in the power sector. The areas of studies include alternatives to lithium-ion storage batteries and green hydrogen for mobility (pib.gov.in, 2023).

5.2.2. Policies and Regulatory Development

In India, the ownership of power generation is divided, with 30% owned by the state government and 25% by the central government. The remaining 45% is privately owned, delivering electricity to either state or privately owned distribution companies. State regulators exercise full control over electricity transmission, distribution, retail and tariff setting.

The Indian government has adopted a proactive stance in establishing ambitious goals for the development of India’s solar energy. Aside from the flagship national solar mission, India leverages its expertise in constructing solar cities, parks, and floating solar facilities. Approval and operation of 59 solar parks, with a combined capacity of 40 GW nationwide, underscore India's commitment to solar energy expansion (Suchadra, 2023).

In terms of solar energy storage, though most states currently lack a regulatory framework for battery storage, India has been making steady progress in creating a market for ESS (WBCSD, 2022). Key policy barriers currently include a lack of provision for storage in energy policies, and targeted support for early adopters of storage technologies.

5.2.3. Key Challenges

India currently faces limitations in the readiness of its grid infrastructure. Distribution companies in India have struggled to integrate renewable energy back to the grid, leading to curtailment of renewable energy output.

Furthermore, the distribution of solar energy facilities in India exhibits significant variability across states. The penetration rate of solar energy varies considerably, with some states having a much higher share of solar and wind energy compared to the national average of 8.2% (IEA, 2021).

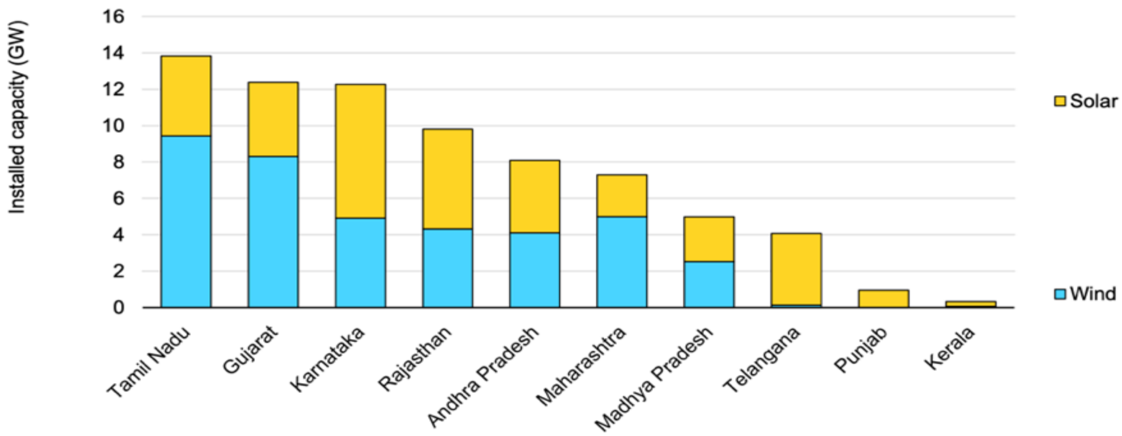

Figure 5.2.2: Solar and Wind Capacity in India's Renewable-rich States (IEA, 2021)

Consequently, leaders in certain states find themselves in the position of needing to export a significant amount of power to other states. This situation poses challenges for the effective integration of renewable energy into the grid.

While India has been ramping up rooftop solar systems, there is a need for heightened focus on monitoring and management. To achieve this, it is essential to register connection nodes for individual rooftop solar assets at both the state and national levels. This registration process enhances data visibility and contributes to more efficient electricity deployment.

5.2.4. Energy Storage Solutions

According to KPMG, India's effective and reliable integration of renewable energies necessitates the deployment of 38 GW of four-hour battery storage (Shukla, 2022). Therefore, India has adopted a comprehensive approach to bolster its energy storage capabilities. At the governance level, India has launched the national energy storage mission, with a robust target of 40 GW storage capacity by 2025 (Jain, 2023). The government has also been actively promoting innovative technologies such as time-of-use tariff to monitor power consumption and storage. In 2023, India's Ministry of Power released pumped storage hydro development guidelines, addressing requirements for variable storage and ancillary services (Ingram, 2023).

Among various energy storage mechanisms, battery storage stands out as the most cost-efficient option, particularly when situated in proximity to solar plants. India has therefore initiated several large-scale battery projects. Most notably, Phyang Solar PV-Battery ESS and AES-Mitsubishi Rohini Battery storage system have been developed with storage capacity of 50,000 kWh and 10,000 kWh respectively. The government also provides businesses setting up battery storage facilities totalling 4,000 megawatt hours (MWh) with subsidies of 37.6 billion rupees ($455.2 million) and intends to provide large-scale battery manufacturers with subsidies totalling $2.5 billion (Singh & Bello, 2023).

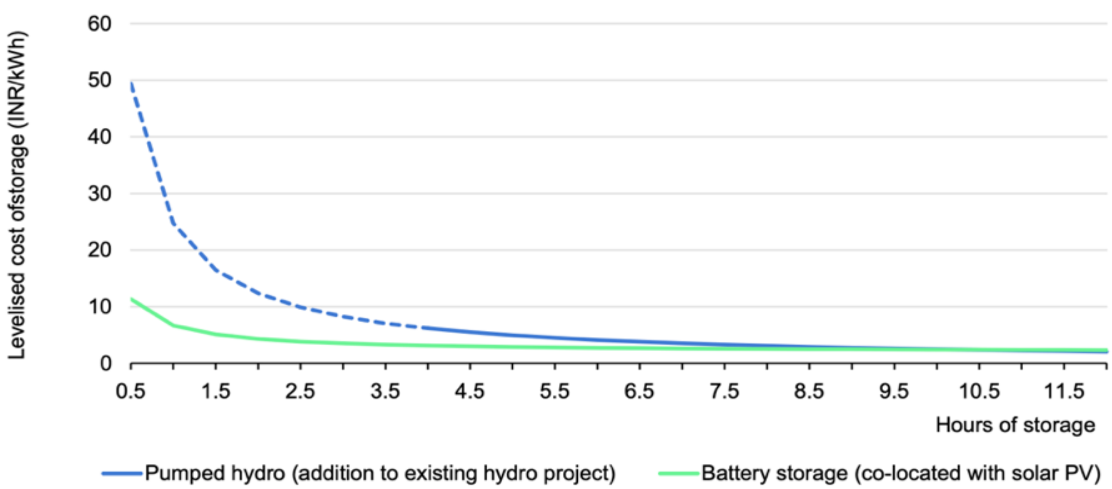

Figure 5.2.3: Levelized Cost of Storage Comparison (IEA, 2021)

5.3. Australia

5.3.1. Overview

Australia stands as one of the most mature economies in terms of renewable energy readiness, with 35.9% of its electricity generation sourced from renewable sources (Clean Energy Council, 2023). With over 3.52 million PV installations, Australia boasts a solar capacity of 32.1 GW (Australia PV Institute, 2023). The nation’s total renewable energy capacity stood at 45.5GW in 2022 (Statista, 2023).

Similar to Vietnam, Australia is naturally endowed with abundant supply of solar resources. The combination of a dry climate and Australia’s latitude contributes to exceptional solar energy production potential. Till date, Australia possesses the highest solar radiation of any continent, averaging 58 million PV solar radiation annually (Australia Trade and Investment Committee, 2023).

Australia has been an early leader in the adoption of rooftop solar systems with the highest penetration of household solar PV installation globally. One in three households have installed solar panels, accounting for 25.8% of Australia’s total renewable energy generation (IEA, 2023). As the cornerstone of Australia’s renewable energy success, the government continues to encourage households to install rooftop solar panels. In 2022 alone, 310,000 rooftop solar systems were integrated to the grid, augmenting the energy capacity by 2.7 GW (Clean Energy Council, 2023).

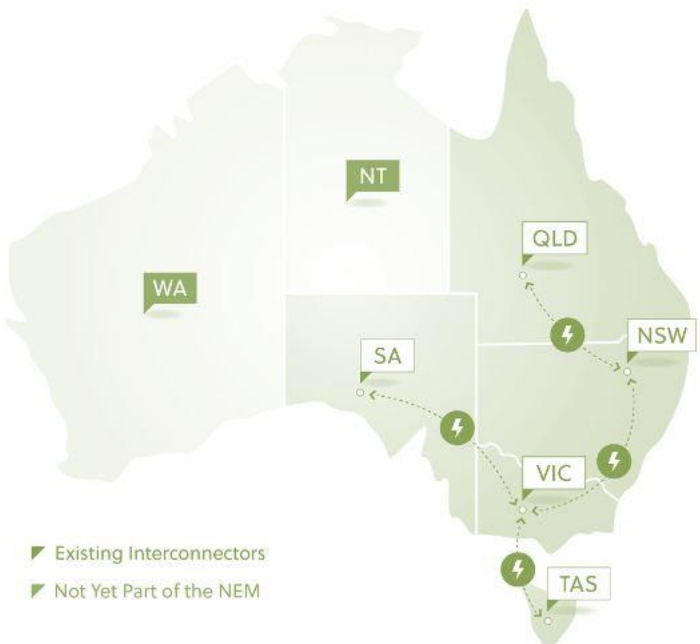

Figure 5.3.1: Australia's Energy Market Segmentation (AEMO, 2022)

Unlike other energy markets, Australia's energy system consists of two wholesale electricity markets, the National Electricity Market (NEM), which operates in eastern and south-eastern Australia, and the Wholesale Electricity Market (WEM), which operates in Western Australia. This paper focuses primarily on Australia's NEM, as it serves as the primary deployment area for solar energy facilities.

5.3.2. Policies and Regulatory Development

NEM's electricity market is primarily overseen by three entities: the Australian Energy Market Operator (AEMO) responsible for regulating energy generation, Australian Energy Regulator that approves the regulatory investment test for transmission and sets network price, and Australian Energy Market Commission (AEMC) that designs the overarching regulatory framework.

To facilitate the seamless integration of solar energy into the power grid, the Australian government has allocated substantial funding to transmission projects. For instance, the government has earmarked $75 million for the design and approvals phase of the Marinus Link project and provided over $250 million in underwriting support for the VNI West project.

The Australian government has introduced clear incentives for both private sector stakeholders and residential battery storage adoption. At the regional level, New South Wales (NSW) has initiated the Emerging Energy Program, allocating $75 million in funding to subsidise energy storage projects within the state. Additionally, eligible homeowners and businesses can benefit from a subsidy of $450 per kWh of usable battery system capacity, up to a maximum of $6,000 (Solar Quotes, 2023).

To encourage renewable energy R&D, the government adopts an R&D Tax Incentive (RDTI) program to support Australian industry-based R&D (KPMG, 2021). In addition, the government has allocated $15 billion to initiate the National Reconstruction Fund (NRF) to offer funding for projects which could "diversify and transform the industry and economy" in a few priority areas including renewables and low emission technologies (Australian Government, 2023).

5.3.3. Key Challenges

Region	Issues	Interim management plan	Long-term management plan
South Australia	Regional fault level shortfall declared in October 2017.	Directions for system strength. Since July 2017, directions have been in place 17% of the time.	Installation of high inertia synchronous condensers by ElectraNet as South Australian TNSP by 2021[A].
	Regional inertia shortfall declared in December 2018.	Directions for inertia and FCAS required under credible risk of islanding.	
Victoria	Inertia and fault level shortfalls in West Murray declared in 2019.	Hold points on NW Victoria generation to manage stability until system strength remediation is complete[B].	Under study by AEMO as Victorian Jurisdictional planner.
Tasmania	Regional inertia and fault level shortfalls declared in November 2019.	TasNetworks has negotiated the provision of inertia network services and system strength services under contract from a provider within the Tasmanian region offering suitable synchronous condenser capabilities.	
Queensland	System strength shortfall declared in North Queensland in April 2020.	Constraints for system strength are currently implemented, requiring minimum synchronous unit combinations and curtailing wind and solar under certain conditions.	Under study by Powerlink, as the local TNSP, with system strength services to be implemented by 31 August 2021.

Figure 5.3.2: Challenges Faced by Australia's Energy System (AEMO, 2022)

With the widespread adoption of solar energy, which is highly dependent on weather conditions, the task of dispatching energy becomes fraught with uncertainty and challenges. While AEMO has dedicated efforts to project potential shortfall in electricity supplies across regions, challenges including variable behaviours of the different solar generators as well as lag between detection and remediation leads to instances of energy short-fall (AEMO, 2022). Nevertheless, AEMO has outlined a comprehensive plan to systematically address this issue.

In addition, the high demand for infrastructure in Australia, driven by the proliferation of solar generating facilities, underscores the need for investment in infrastructure development. Despite substantial investment in infrastructure, certain areas continue to face limitations due to outdated infrastructure with thermal constraints and system strength issues (AEMO, 2022). Additionally, Australia's transmission lines are often located in areas traditionally associated with fossil-fuel electricity generation sites and therefore far from renewable sites. This mismatch implies that regions with ideal weather conditions may lack the transmission infrastructure to capture renewable energy.

Australia's adoption of residential solar PV has also encountered technical bottlenecks. NEM, for instance, has faced an increase in contingency size due to solar PV disconnection in response to major system disturbances. To date, an effective governance structure has yet to be established to formalise a pathway for power system security and ensure consistent compliance with technical performance standards across all residential solar PV installations (AEMO, 2022).

5.3.4. Energy Storage Solutions

Australia has emerged as a front-runner in the field of energy storage solutions, with the support of substantial government funding initiatives. By the end of 2020, the country had 16 large-scale battery projects under construction, collectively representing an impressive 595 MW of new capacity (Solar Emporium, 2023). Households continue to be incentivized to adopt residential solar batteries. Overall, battery storage capacity is expected to increase 28% by 2032 (Hazarika, 2023). This is contributed by market players such as ShineHub who were very good at selling solar and batteries, particularly overcoming the obstacles associated with selling batteries. Compared to the industry average of 13%, 70% of ShineHub's solar systems are sold with batteries. Then ShineHub acquired the skills necessary to manage a battery fleet. After establishing a solid customer and income base, ShineHub created their own hardware-free, vendor-neutral VPPs software that controls batteries directly. To maximise the potential of market integration, they subsequently built ties with networks and merchants. When clients of ShineHub participate in their VPP, AusGrid now pays 45c/kWh for that event (energystorageforum, 2020).

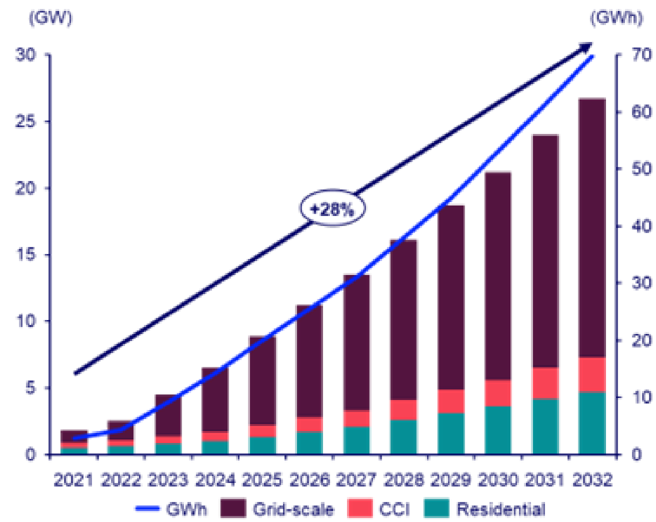

Figure 5.3.3: Australia's Projected Energy Storage Capacity (Wood Mackenzie, 2023)

The integration of batteries into VPPs has been a key initiative the Australian government is working on. This strategic move involves the collection of data from each battery unit and leveraging artificial intelligence to analyse demand and supply patterns. As VPP matures, AEMO could yield better outcomes for both local and regional electricity grids and facilitate a more efficient energy market pricing system (Clean Energy Council, 2023). In the future, rooftop solar and batteries are likely to be replaced by solar and EVs because they have two benefits over stationary storage. Firstly, EVs have bigger batteries. The majority of EVs have six to ten times the capacity of small-scale batteries (electric trucks and buses have much more capacity). Secondly, they are mobile as they can be driven to charge from various sites. Therefore, the EV and V2G (Vehicle to Grid) is seen as a game changer for ESS (Kuiper, 2022).

Additionally, Australia has a well-developed smart metering system to effectively track and manage energy usage across the nation. Smart metres are Internet of Things (IoT) facilities to monitor real-time energy, water, and natural gas consumption. Smart metres replace traditional analog metres and offer improved efficiency, accuracy (Jantti et al., 2022). Working in synergy with VPPs, smart metres help to implement demand response programs: households utilise batteries to store excess energy generated on rooftop solar and VPP consolidates thousands of households with rooftop solar batteries. Through smart metres, households can see real-time prices and consumption patterns, and choose to discharge extra energy stored in their own batteries into the wholesale market when price is favourable, establishing a “prosumer” scheme (Kaur, 2021). With greater transparency of metering information coupled with appropriate incentives, smart metering can help increase energy efficiency, change consumers’ behaviour and reduce emission (Jantti et al., 2022). This year, the Australian Energy Market Commission (AEMC) has made plans to enhance the framework for smart metering, aiming to ensure 100% of consumers have smart metres by 2030. This is expected to contribute $507 million for the national electricity market (Packham, 2022).

5.4. Malaysia

5.4.1. Overview

In 2022, the total renewable energy capacity in Malaysia amounted to approximately 9.0 GW. The capacity of renewable energy in the country has increased by more than 3 GW since 2013. As of 2023, Malaysia's energy landscape is primarily dominated by fossil fuels, accounting for a substantial 95% share of the country's energy mix over the past decade. Estimates from the International Renewable Energy Agency (IRENA) indicate that renewables presently contribute to only 5% of Malaysia's energy mix with hydropower and solar making up the majority (Tachev, 2023).

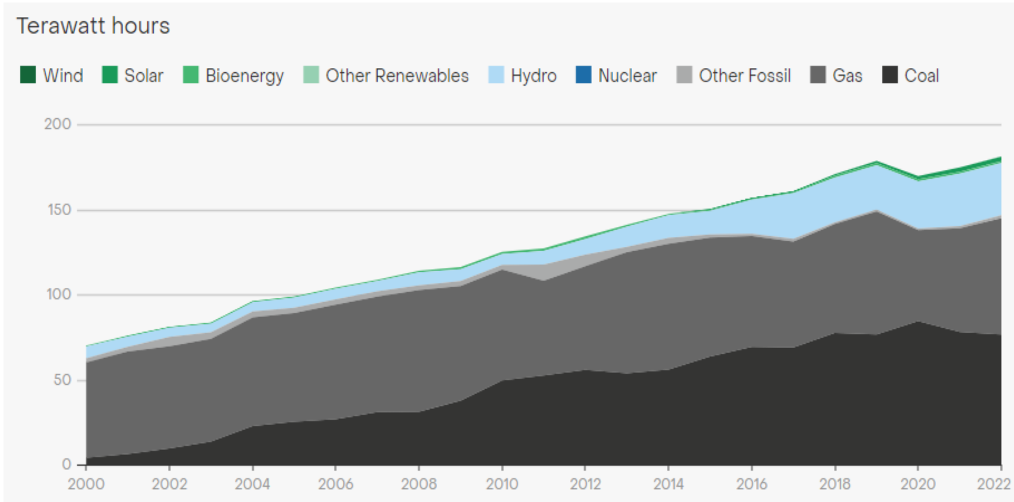

Figure 5.4.1: Malaysia Electricity Generation by Source (Ember, 2023)

Malaysia's favourable geographical location near the equator provides abundant solar resources, which drives the growth in Solar PV. The declining costs of solar PV technology have improved its cost competitiveness, making it increasingly attractive for investors and energy consumers. Therefore, Malaysia has effectively stimulated investment in renewable energy, with a particular focus on solar PV. This investment has played a crucial role in nurturing the entire value chain industry, encompassing the manufacturing of renewable energy equipment, its installation, and the subsequent generation of energy (Bernama, 2023).

Malaysia has an advantage given its proximity to Singapore. Using the ASEAN grid interconnection effort, renewable energy trade seeks to place Malaysia at the centre of the regional power trade. Singapore is a low-hanging fruit because it has several RE100 MNCs in the region and doesn't have enough land to support renewable energy generation. RE100 is a global movement involving businesses who are committed to using 100% renewable energy throughout their operations (Editor, 2023). Crucial to Malaysia's successful renewable energy export venture is the establishment of a robust infrastructure and seamless integration with Singapore's power grid, estimated to cost an astounding US$143 billion encompassing funding for new renewable energy generation sources, grid infrastructure reinforcement, ESS integration, and operational expenses to ensure a smooth and efficient energy transfer (Kaur Kawan Singh, 2023). For the future development of renewable energy, Malaysia has pilot projects aimed at improving the conversion of biomass into energy and designating Sarawak as a green hydrogen development hub (Guild, 2023).

5.4.2. Policies and Regulatory Development

The Malaysian government's energy policy involves several significant parties. The Economic Planning Unit (EPU) of the Prime Minister's Department focuses on petroleum energy and privatisation of electricity supply. The Ministry of Energy, Green Technology, and Water (MESTECC) oversees electricity supply, energy efficiency, and renewable energy, while the Ministry of Rural Development works on rural electrification. The power and natural gas industries are governed by The Energy Commission (EC) (AGEP, 2019).

The Malaysian government has implemented supportive policies and incentives to foster renewable energy development. To reduce monthly electricity costs, consumers are encouraged to install renewable energy sources, such as rooftop solar installations. The government introduced initiatives like the FiTs scheme, which evolved into the Net Energy Metering (NEM) program. FiTs and tax incentives encourage investment in solar PV projects by providing stable and long-term contracts for renewable energy producers. Under NEM, consumers can offset their energy consumption with energy generated from their solar panels (Lau et al., 2022).

Energy storage becomes essential for realising VPPs within the grid system for commercial and industrial consumers with larger-scale solar generation. The Net Offset Virtual Aggregation (NOVA-VPP) program allows excess stored energy to be exported back to the grid, enhancing control over energy dependency (Ditrolic Energy, 2022). Malaysia has also introduced a virtual power purchase agreement (VPPA) programme, which is between a solar power producer with a BESS system and a corporation (Skrine, 2022).

5.4.3. Key Challenges

Despite the promising growth, Malaysia faces several challenges in meeting its renewable energy targets. Firstly, the targets set by Malaysia’s government are unrealistic. The government's targets of achieving 31% renewable capacity by 2025 and 40% by 2035 may be difficult to attain, given the current growth trend, which suggests achieving only 12.1% renewable capacity by 2025 and 22.7% by 2035 (Energy, 2023). Solutions include setting more achievable targets and implementing robust policy support. Malaysia should look to create partnerships to enable technology transfer to improve efficiency of renewable power plants. A detailed policy with a clear roadmap and strict implementation measures is required for renewables growth.

Secondly, there is a lack of large-scale renewable projects for Malaysia. Malaysia struggles to attract investment in large-scale renewable projects due to a sluggish economy and unclear policy. Enhancing infrastructure availability, grid capacity, stability, and flexibility are crucial for scaling up renewables and connecting with neighbouring countries. Streamlining project approval processes and enhancing the financial environment by introducing both new and existing mechanisms such as Power Purchase Agreements (PPAs) and tariff adjustments (Tachev, 2023). These measures aim to facilitate and encourage large-scale renewable projects. Malaysia should establish a transparent electricity market and effectively launch renewable energy projects to establish a robust track record. Currently, the lack of such a track record makes financial institutions cautious. Building a strong foundation of successfully implemented renewable energy projects will attract more funding and expand local industry expertise, positioning the country as an appealing destination for both investors and project developers.

5.4.4. Energy Storage Solutions

Due to its equatorial location, Malaysia boasts some of the highest solar power potential in the world. As a result, the government has taken a more active role in identifying regions that would benefit from the development of solar power, particularly BESS in Malaysia. Companies like Citaglobal Genetec have launched Malaysia's first locally developed BESS to address large-scale energy storage and portability needs, aiding in rural electrification and grid integration (Chong, 2023). As Malaysia increases its renewable energy penetration into the grid, there is a growing need for BESS to balance and stabilise the grid.

Malaysia is exploring the repurposing of retired EV batteries as energy storage solutions. This approach can lower costs and enhance energy storage capabilities, contributing to grid stability. A recent MIT study has identified specific parameters for second-life batteries to attain commercial viability: 1) The reuse project should have a long project life, exceeding 16 years ; 2) After 16 years of operation in the second-life application, these batteries should still retain at least 60% of their initial capacity; 3) The cost of spent batteries should be less than 60% of new batteries. Leading automakers are investigating uses for retired EV batteries rather than disposing of them. Reusing retired EV batteries for various purposes, such as solar-powered kiosks, portable chargers, household energy storage, and portable battery banks for EVs, is the goal of projects like BMW Group Malaysia's RE:GENERATE program in Malaysia. This strategy fits with the expanding market for Second-Life Energy Storage Systems (SLESS), where old EV batteries are given a second chance at aiding the grid integration of renewable energy sources (Lee et al., 2023). Overall, as EV usage rises, battery technology develops, and the demand for sustainable grid solutions grows more pressing, the possibility of second-life energy storage in Malaysia and other nations is anticipated to expand.

However, research on SLESS in Malaysia is still in its early stages due to slow adoption of EVs and grid-integrated ESS. The current market design for ESS is less accommodating for distribution networks, despite the government's push for renewable energy. To accelerate ESS adoption, energy storage policies can be introduced to encourage investment in research and development, provide incentives, and enhance energy security.

5.5. New Zealand

5.5.1 Overview

In 2022, New Zealand's total renewable energy capacity amounted to approximately 8.1 GW. As of 2022, renewable energy sources already account for approximately 87% of the net electricity generation mix, setting a strong foundation for further expansion (MBIE, 2023). The government has set ambitious targets, including achieving 100% renewable energy generation by 2030 and net-zero emissions by 2050. One of the key drivers of this growth is the government's commitment to transforming the country into a green economy, with a substantial share of renewables in its total primary energy consumption. In 2022, New Zealand has allocated 2.7% of the government budget for renewable energy development (New Zealand Government, 2022).

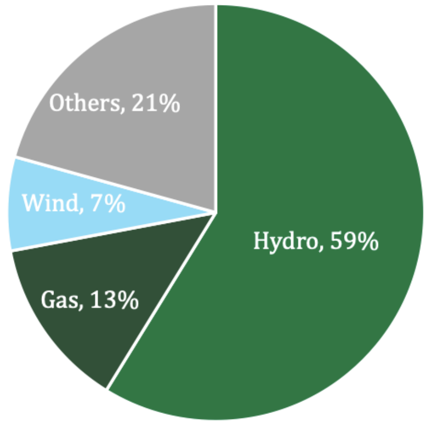

Figure 5.5.1: Distribution of Electricity Generation in New Zealand in 2022, By Source (Lee et al., 2023)

The transformation of New Zealand's power system is driven by four key factors:

- Decarbonization of the Electricity Industry: This involves reducing greenhouse gas emissions by increasing the use of renewable generation sources like wind and solar PV while reducing reliance on gas and coal-based generation.
- Decarbonization of the Wider Economy: New Zealand seeks to reduce fossil fuel usage by increasing electrification across various sectors, including process heat and transportation.
- Distribution: The adoption of Distributed Energy Resources (DER), such as solar PV, EVs, batteries, and smart appliances, is growing throughout the power system.
- Digitization: As the volume of data and the complexity of managing energy resources increase, digital tools become essential for effective management (Transpower New Zealand Ltd, 2021) .

Opportunities & challenges	Timeframe	Priority
Leveraging DER to build and operate the future grid	3-7 years	Medium
Leveraging new technology to enhance ancillary services	Enduring	Low
Visibility and observability of DER	3-7 years	Medium
Balancing renewable generation	3-7 years	Low
Managing reducing system inertia	7-10 years +	Low
Operating with low system strength	3-7 years	Medium
Accommodating future changes within technical requirements	0-3 years	High
Coordination of increased connections	0-3 years	High
Loss of control due to cyber security	Enduring	Medium
Growing skills & capabilities of the workforce	Enduring	High

Figure 5.5.2: Timeframe and Priority for the Opportunity or Challenge for the Transformation (Transpower New Zealand Ltd, 2021)

5.5.2 Policies and Regulatory Development

The Minister of Energy and Resources oversees a wide range of markets for energy, including those for electricity, gas, liquid fuels, and resources (such as minerals and oil). The regulatory steward of the resources and energy markets is the Ministry of Business, Innovation and Employment (MBIE). Its main responsibility is to advise the minister or government on energy and resource policy. The Commerce Commission oversees regulating competition. The scope of its authority includes economic regulations on natural monopoly infrastructure services, such as power grids, gas pipelines, telephones, and airports. The Electricity Authority manages the electricity industry and enforces market rules, while state-owned enterprise Transpower owns and operates New Zealand's national electricity transmission system (IEA, 2023).

The Emissions Trading Scheme (ETS) is one of the major factors encouraging investment in renewable energy projects in New Zealand. ETS requires companies to track and report on their greenhouse gas emissions. It also requires companies to provide the government one "emissions unit" (often referred to as a NZU) for every tonne of emissions they produce. The scheme limits the amount of NZUs that are available to emitters and businesses can buy and sell units from each other (Ministry for the Environment, 2023). The scheme significantly increases businesses’ interests and investments in renewable energy projects as they need to follow the government's requirement by reducing the emission unit of their businesses. Furthermore, MBIE established funds for community-based renewable energy projects, including grants for the development costs of projects, and fund implementation costs. This initiative focuses on low-income communities and/or insecure access to energy.

In the realm of energy storage solutions (ESS), New Zealand has government initiatives such as The NZ Battery Project. Private sector investments in this realm are also noteworthy, with Meridian Energy's 100MW Ruakākā Battery BESS currently under construction and expected to be operational by the third quarter of 2024 (Trixl, 2023). However, New Zealand should increase policy focus and support on ESS to enhance participation from individual, commercial and industrial consumers.

5.5.3 Key Challenges

Despite New Zealand's high proportion of renewable electricity, challenges persist, particularly concerning the electricity system's heavy reliance on hydropower, which accounts for over 50% of generation. The main challenge is the "dry year problem" when hydro inflows are low, and backup from fossil fuel generation is required. One cannot forecast when or how long a "dry year" will persist, but they often linger for a few months. As a result of rain being frozen into ice and snow, they are more likely to happen during the winter months when hydro lakes receive less water (IEA, 2023). The need for electricity to heat homes and other buildings is rising at the same time as this.

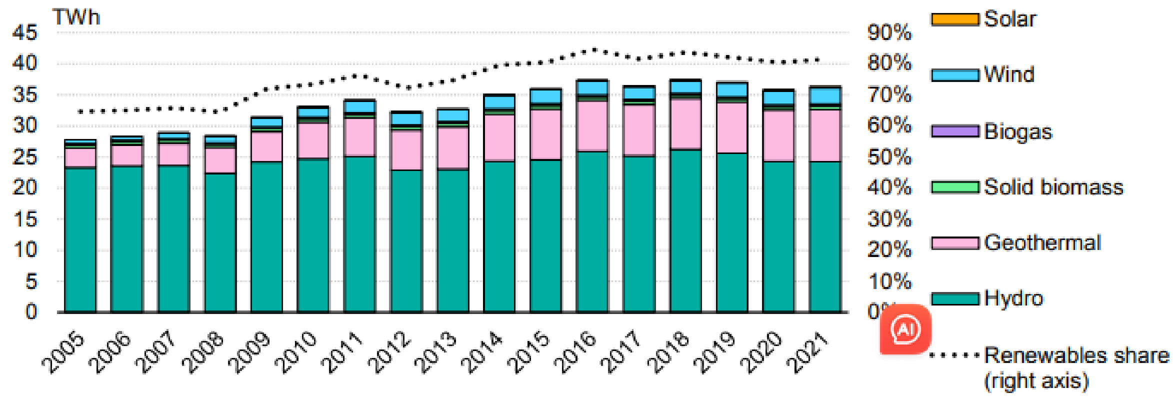

Figure 5.5.3: Renewable Energy in Electricity Generation in New Zealand, 2005-2021 (IEA, 2023)

To address these challenges and further promote renewable energy, New Zealand has partnered with U.S. investment firm BlackRock. Together, they have established a NZ$2 billion fund to accelerate investments in green energy projects, including solar, wind, green hydrogen, and battery storage. This partnership is part of New Zealand's broader efforts to achieve a 100% renewable electricity supply, estimated to require significant investments totaling NZ$42 billion (Brockett, 2023).

5.5.4 Energy Storage Solutions

New Zealand has approved the development of its largest planned BESS, with a capacity of 100MW. This project, led by Meridian Energy, is set to enhance grid stability by smoothing supply and demand fluctuations (Colthorpe, 2022). It will charge during off-peak hours and discharge during periods of high demand, facilitating the power generated on the South Island to be utilised in the northern.

To address the dry year problem without relying on fossil fuel, the government initiated the NZ Battery Project in 2020. The initiative will offer thorough guidance on the commercial, technical, and environmental viability of various energy storage facilities. The term "NZ Battery" refers to the way the proposed solution, whether it involves pumped storage or another method, will store energy for the New

Zealand power grid in a way similar to a battery. In order to reach 100% renewable electricity and support the decarbonization of the larger energy system, the first phase will assess the most effective way to address New Zealand's dry year electricity storage challenge. It will include a thorough evaluation of potential dry year solutions, such as the Lake Onslow Pumped Hydro Project (which preliminary studies determined to be technically feasible). It is designed to thoroughly study demand-side options, coupled with smaller pumped storage options, and alternative technologies (IEA, 2023). The government's decision to proceed with the second step, which would involve engineering design and preliminary work on a selected solution, will depend on the outcomes of the first phase. Construction would take place in the final phase, assuming Cabinet approval. The project's feasibility studies are anticipated to be finished in 2023, and solutions should be in place by the 2030s.

5.6. Philippines

5.6.1. Overview

The Philippines, alongside Indonesia, boasts one of the highest concentrations of geothermal power generation in Asia and possesses the world's third-largest installed geothermal power capacity at 1,918 megawatts (MW), trailing only the United States. The country's total renewable energy capacity stands at 7.1 GW, with over half of it (4.3 GW) coming from hydropower and an additional 896 MW from solar energy (Tachev, 2022). The demand for solar energy is expected to surge in the near future due to a significant pipeline of approved and under-development projects.

Aligned with its National Renewable Energy Program (NREP) 2020-2040, the Philippines aims to have renewables contribute 35 percent of power generation by 2030 and 50 percent by 2040. This entails a 75 percent increase in geothermal capacity, a 160 percent expansion in hydropower capacity, raising wind power capacity to 2,345 MW, and incorporating an additional 277 MW of biomass power. Despite these goals, the country's transition to renewables has witnessed a declining trend, with renewable energy accounting for just 26 percent of power generation in 2022, down from 34 percent in 2008 (Chipman Koty, 2023).

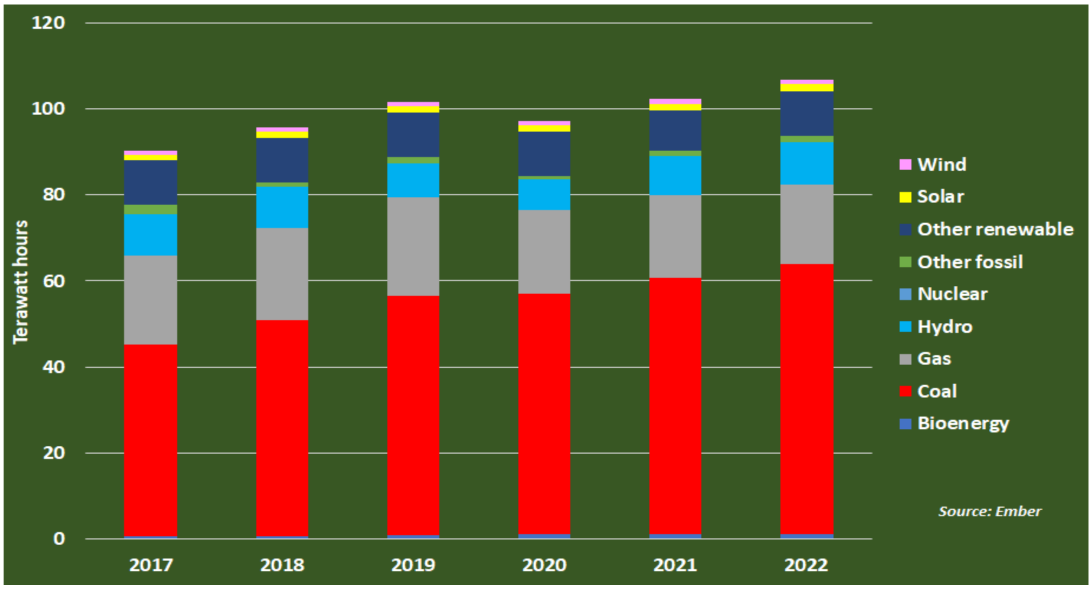

Figure 5.6.1: Power generation by sources in the Philippines (Maguire, 2023)

In a move to boost its renewable energy sector and meet long-term climate targets, the Philippines has opened up renewable energy to full foreign ownership. Foreign investors can now hold 100 percent equity in the exploration, development, and utilisation of solar, wind, hydro, and ocean or tidal energy resources (Chipman Koty, 2023). The government recognizes the need for substantial investments, estimated at US$120 billion by 2040, to achieve its renewable energy objectives. Furthermore, the Philippines is developing a renewable energy model for developing countries that can provide electricity as reliably as coal or natural gas. Virtual synchronous generator (VSG) technology was designed to juggle large amounts of renewable energy in this project (Shiga & Shigeno, 2023).

5.6.2. Policies and Regulatory Development

The National Power Corporation is a government-owned and controlled corporation in the Philippines with the responsibility to manage water resources for power generation, to maximise the use of other power-generating assets, and to deliver electricity to all of the country's rural areas by the year 2025 (NPC 2023). In the Philippines, power generation is not regarded as a public utility operation, therefore potential owners do not require a congressional franchise to run a power generation business. To make sure that the requirements outlined in the Electric Power Industry Reform Act of 2001 (EPIRA) are fulfilled, the Energy Regulatory Commission (ERC) must issue a certificate of compliance to interested parties in order to regulate power generation (Department of Energy, 2023). The ERC is also in charge of power abuse or anti-competitive behaviour. The transmission system in the nation is run and maintained by the National Grid Corporation of the Philippines (NGCP). NGCP is a private corporation which ensures that power is transmitted across the archipelago in an efficient and reliable manner (NGCP, 2023). However, 40% of NGCP’s shares are owned by China’s State Grid Corporation. Following worries expressed by some of the country's politicians about China's access to the country's power infrastructure, the Philippines is stepping up security procedures to safeguard its energy sector from foreign intervention, according to its national security adviser (Reuters, 2020).

Renewable energy development in the Philippines is primarily governed by the Renewable Energy Act, which provides a variety of incentives such as a seven-year income tax holiday and FiT scheme for eligible renewable energy developers. The government also introduced a net metering system to promote usage of renewable energy. A net metering is a system that is suitable for distributed generating. A distribution grid user that uses net metering has a two-way connection to the grid, is only charged for his net electricity consumption, and is given credit for any total contribution to the electricity grid (Natalie, 2023).

The combination of renewable energy and energy storage is considered as the most feasible collaboration that could undermine the dominance of traditional fossil fuels in the energy mix. The Philippines Department of Energy (DOE) has introduced new draft market rules and policies for energy storage (Murray, 2023). This follows the recent allowance of 100 percent foreign ownership of renewable energy assets. The DOE aims to be more adaptable and change the legal framework governing the investment and deployment of energy storage technologies in the nation.

5.6.3. Key Challenges

In the first half of 2021, 17 power-generating companies in the Philippines experienced unplanned shutdowns, exceeding their allowable outage periods. This led to manual load dropping measures to maintain grid stability. Rolling blackouts, typically confined to hot months when hydropower supply is limited, extended into July, causing disruptions in education and work for many. Renewable energy offers a solution by ensuring electricity access for all and reducing costs for consumers. Despite progress in electrification, around 2 million people in the Philippines still lack access to electricity (Apanada & Kaldjian, 2021). Decentralised, decarbonized power generation systems that avoid the need for expensive transmission networks in remote areas can contribute to total electrification.

Access to capital is still a major issue. Only a few local banks now lend money to renewable energy projects in the area. In addition, funding has significantly decreased in recent years. For instance, they experienced a $77% decline of $300 million in 2019. According to the International Renewable Energy Agency, some of the biggest problems involve expensive upfront and technological expenses, and complexity of the regulatory environment (Tachev, 2022). Renewable project developers face significant difficulties because of the regulatory environment's complexity, processes' fragmentation, and lengthy permit application timelines. The nation has a fragmented permitting system, and different agencies are in charge of issuing these permits. This system may cause delays in obtaining necessary licences, costing project developers a lot of money. Although the Energy Virtual One-Stop Shop, or EVOSS platform, created by the government has addressed this issue, much work remains (Aboitiz Renewables Inc., 2023). Streamlining regulatory processes and timelines is essential to attract investment and expedite project development.

Any investor, regardless of nationality, wants policy certainty, which is probably lacking in the Philippines. Investor perception of unclear government signals and policies is evident (Garcia, 2023). Government should be proactive in removing barriers to investments rather than passively waiting for them to happen.

5.6.4. Energy Storage Solutions

Over the past few years, power companies in the Philippines have been developing large-scale battery storage infrastructure. The Philippines has inaugurated the San Miguel Corporation's (SMC) BESS, a significant step toward energy security and innovation. This 1000 MW BESS facility positions the Philippines as a leader in energy storage. Moreover, A 49 MW BESS project at a floating diesel power barge has just been finished, according to current news from Aboitiz Power (Colthorpe, 2022). The Philippines' major power companies are competing with one another for operational efficiency at their power generation fleets, which is enhancing the development of the battery storage market.

In the Philippines, it is against the law for generation companies to own more than 25% of the installed capacity nationwide or more than 30% of the installed generation capacity on each of the island country's grids (Colthorpe, 2022). As major generation companies are presently the first investors in large-scale battery storage in the Philippines, they may be hindered from implementing battery storage if it implies that threshold will be exceeded. The Philippines Department of Energy (DOE) and authorities are reviewing the ownership regulations for grid-connected ESS.

There is also a growing recognition of the need to redefine energy storage and facilitate investment in grid-connected ESS. The DOE classified at least four energy storage technologies, including BESS, Compressed Air Energy Storage Systems (CAES), Flywheel Energy Storage Systems (FESS), which are expected to enhance the country's ESS capacities in the near future (VELASCO, 2023).

5.7. Thailand

5.7.1. Overview

Thailand is ranked no. 4 in Asia and no. 3 in ASEAN (after Singapore and Malaysia) and is considered a "Leader" by the World Economic Forum in its Energy Transition Index, an index which ranks countries on the performance of their ability to incorporate renewable energy into the grid. Additionally, Thailand, the largest producer of solar energy in Southeast Asia, aims to increase the proportion of renewable energy used to produce electricity to 50 per cent in 2050, up from 20 per cent in 2021 (Economic Development Board, 2022)

Historically, similar to most other Southeast Asian countries, energy generation in Thailand has mostly been produced by burning fossil fuels. Aligned with the global aspiration of net-zero, Thailand has affirmed their commitment for renewable energy to make up at least 30% of power generating capacity by 2037, up from the current 14.9% in 2022. This 14.9% of renewable energy generation can further be broken down to 30% biomass, 25% hydropower, 24% solar, 13% wind and 8% waste and geothermal.

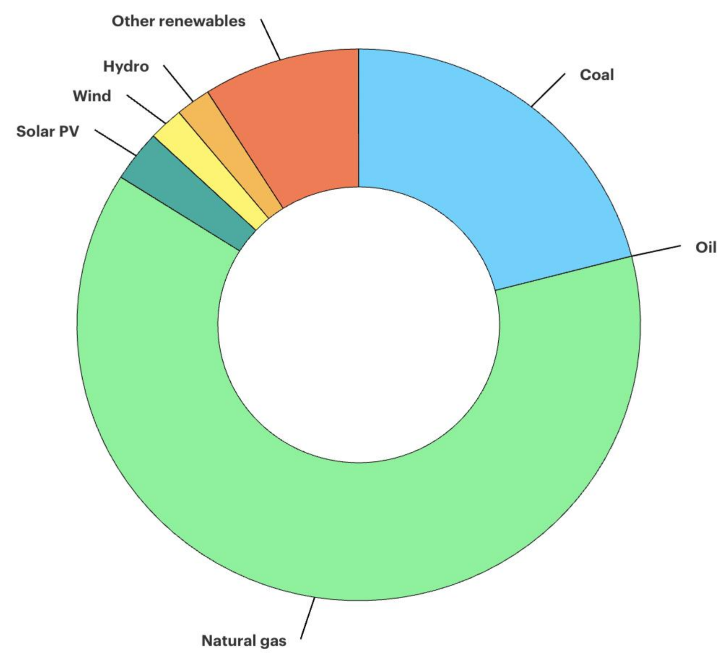

Figure 5.7.1: Breakdown of Thailand's Energy Market (IRENA, 2020)

Thailand has a relatively diverse installed renewables base, not relying on a single primary generation source such as hydropower or solar like many regional neighbours (Modi & Lackovic, 2021). Recent expansion has focused on wind and solar technologies, with impressive annual growth of 89% and 83% respectively over the last decade.

While future projections show notable headwinds for wind power, solar is predicted to increase sevenfold from 2,633 MW in 2021 to 14,864 MW in 2037. The Ministry of Energy's (MOE) Power Development Plan 2023 (PDP23) outlines that solar offers the clearest opportunity for significant renewable energy development.

Solar presents the most attractive path for financial institutions and investors, driven by the government's overarching commitment to advancing renewable energy at a national level. Additionally, it is bolstered by various incentives designed to attract and reward investors.

5.7.2. Policies and Regulatory Development

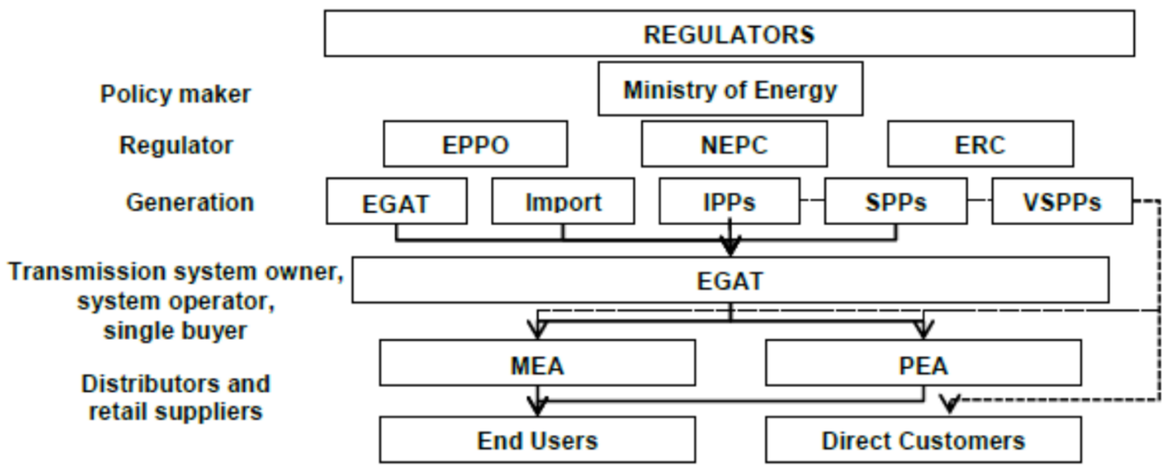

Figure 5.7.2: Structure of Thailand's Power System (Energy Regulatory Commission, 2012)

The energy sector in Thailand is governed by the Ministry of Energy and Managed by the National Energy Policy Council (NEPC). NEPC's main objective is to develop and suggest national energy policies to the government. The Energy Policy and Planning Office (EPPO) is responsible for drafting energy related policies for the NEPC. The energy sector in Thailand is regulated by the Energy Regulation Commission (ERC), an independent entity which reviews tariffs, issues licences, approves power purchases and reviews energy market conditions.

The energy market in Thailand follows a single-buyer model. State-owned utility, Electricity Generating Authority of Thailand (EGAT), allows limited private sector participation in electricity generation while maintaining control over system planning and pricing. EGAT owns and manages the majority of the nation's electricity production capabilities, as well as the entire transmission infrastructure. EGAT sells all the power it generates to two state-owned enterprises, namely the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA) who distribute power to the end users. EGAT sells power to these entities at a regulated rate set by the EPPO.

The government has allowed the private sector to engage in renewable energy power generation. The small power producer program allows private developers to build, own, and operate renewable energy power projects and to enter into power purchase agreements with EGAT. Under a separate program for very small power producers, private firms generating less than 10 MW of renewable energy can sell power to MEA or PEA. Small and very small power producers using renewable energy are eligible for a FiT on top of the wholesale electricity price.

EGAT has realised the importance of integrating future renewable electricity generators into the power grid development plan. As stipulated in PDP 2015, EGAT has the obligation to purchase all the electricity generated from renewable energy sources (IRENA, 2017). This requires EGAT to upgrade and expand its transmission networks to be capable of accommodating a growing share of renewable energy (Asian Development Bank, 2016).

The Thai government has developed The National Energy Plan, or NEP (2018-2037), is a long-term energy plan that provides strategic energy directions and guidelines by combining top-down and bottom-up methodologies, with the goal of reaching 50% renewable energy share of all energy types by 2050 (Praiwan, 2022).

The Thai government also supports renewable energy investment projects through The Board of Investment (BOI) for tax incentives and The Energy Conservation Promotion Fund (ENCON) for project financing. The ENCON fund is funded by levies imposed by the government on petroleum products. These incentives were developed to encourage investment in utility scale renewable energy-related projects as well as to incentivize individual companies to invest in generating electricity through renewable means like solar energy for their own use (The Nation, 2023).

It is one of the biggest non-budgetary funds (in terms of its annual budget) for the promotion of renewable energy and energy conservation in Asia-Pacific (United Nations Development Programme, 2012). These funds are controlled by the Thai government and provide for a wide range of solutions such as R&D, working capital, grants and subsidies for investment in energy conservation programs in both public and private sectors (United Nations Development Programme, 2012). Although the fund provides for a diverse range of solutions, there are specific programmatic instruments to target particular beneficiaries as different beneficiaries have distinct characteristics and objectives. The Energy Efficiency Revolving Fund (EERF) and the Energy Service Company (ESCO) Fund are two notable components under ENCON Fund which aim to improve access to finance, targeting the key barrier in energy efficiency and renewable energy projects in Thailand (Wang et al., 2013). They worked well to boost involvement among commercial banks and the private sector in the space of energy efficiency.

5.7.3. Key Challenges

Thailand faces three key challenges when it comes to renewable energy implementation. The first challenge is a fragmented authoritative structure which leads to poor planning, policy uncertainty and discontinuity. There is poor coordination amongst the several institutions at the top. The PDP which was launched in 2018 was supposed to span from 2018-2037 but has since undergone several revisions due to changes in energy policy (Praiwan, 2022).

Another challenge for Thailand is that they are lagging behind in solar adaptation. While Thailand is highly rated by the World Economic Forum (WEF) on its renewable energy transition potential, as of 2021 it was ranked last out of the 16 countries tracked in HIS-Markit's Clean Power Additions Rankings – Renewable Additions Index (RAI). The RAI tracks renewable energy power project capacity under development in Asia Pacific. Only 3% of its planned energy capacity expansion in 2021 was comprised of renewables (Tractus, 2022). So, while the potential is there, Thailand is still falling behind in its implementation of solar energy generation.

Lastly, Thailand's energy market is largely government owned. Thailand could benefit from liberalising their energy market by attracting much needed investment and competition which could see renewable energy technology get adopted more rapidly.

5.7.4. Energy Storage Solutions

Although Thailand is a regional leader in renewable energy, its use of energy storage is nascent. EGAT undertook some studies on the potential for energy storage and is piloting three battery energy storage installations. In May 2020, The Asian Development Bank (ADB) signed a loan with Lomligor Company Limited to finance a 10 MW wind power plant - the first private sector initiative in Thailand to integrate utility-scale wind power generation with a battery ESS capable of storing just 1.88 MW (Asian Development Bank, 2020). However, ESS is widely seen as a vital technology to allow for greater use of intermittent renewable energy (such as wind and solar) within electricity grids. Thailand would have to increase its ESS capacity to facilitate its goal of having 30% of its energy generated by renewable sources in 2037.

5.8. Japan

5.8.1. Overview

In order to achieve Net-Zero GreenHouse Gas emissions by 2050, Japan actively expands the introduction of renewable energy. The Japanese government aims to increase the country's renewable power generation target from the previous 22%-24% to 36%-38% by 2030 (GlobalData Energy, 2022). Specific to solar power, the Japanese environment and trade ministries published the target to achieve 108GW of solar power capacity by 2030, up-scaling its previous 64GW target by 1.7 times (Rai-Roche, 2021). In the realm of battery storage, Japan has aimed to construct 3 to 4 GW of storage capacity by 2030 (Spherical Insights, 2023). Japan has also aimed to bolster its battery manufacturing infrastructure and operations both locally and globally and achieve full commercialisation of solid-state batteries by 2030. In the long term, the government aims to achieve carbon neutrality by 2050.

Unlike many countries, Japan has limited renewable resources. The cost of generating renewable energy is approximately twice as high as in many European countries (Rana, 2020). In terms of solar power, its high price level is due to the relatively high installation and building costs, and the cost of modules and inverters (IRENA, 2021). To incentivize renewable energy production, Japan introduced FiTs in 2012, leading to rapid progress in renewable energy projects.

As a result, Japan emerged as a leader in solar energy in the early 2000s and has since maintained installations of approximately 5 GW per year (HUTCHINS, 2023). By 2022, Japan has built 74 GW of solar PV installation capacity and solar PV accounted for 10% of total power generation (Ohbayashi, 2022). Solar

PV power has grown substantially, surging from 0.4% of overall power generation in 2011 to 6.0% in 2018 (Clifford Chance, 2021).

Besides energy production, power grid infrastructure is another essential element in promoting renewable energy development. Japan's power system has sufficient capacity to accommodate a larger proportion of renewables than is currently provided for in the government's 2030 targets, while still maintaining grid stability (Merk et al., 2018).

5.8.2. Regulatory development

The energy industry in Japan is regulated by the Ministry of Economy, Trade and Industry (METI). METI aims to create responsible energy policy, overcome resource scarcity, foster competition in the private sector, and leverage energy-saving and environmental technology.

To enhance solar energy generation, the Japanese Ministry of the Environment has announced a budget of ¥300 million for solar power generating projects developed on farms, reservoirs, and garbage disposal sites (Bhambhani, 2022). As part of the ¥116.2 billion subsidies, the metropolitan government is promoting the installation of solar panels on buildings by lowering the initial installation cost (KYODO NEWS, 2022).

In a concerted effort to bolster its renewable energy storage development, the government has enhanced its storage battery industry strategy. First, it seeks to strengthen the manufacturing infrastructure for liquid lithium-ion batteries through substantial investments, the procurement of resources, and the establishment of a domestic manufacturing base. It would subsidise up to half the costs of mine development and smelting projects of Lithium and rare-earth metals to support battery development (Nikkei Asia, 2023). Japan provides up to $1.8 billion in subsidies for storage battery and chip projects

(Leussink, 2023). Second, it aims to expand the global presence of prominent companies by strategically establishing overseas operations utilising Japanese technology (Zissler, 2023). Lastly, Japan aims to achieve full-scale commercialisation of all-solid-state batteries by 2030 so as to maintain its technological leadership (METI, 2022).

5.8.3. Key Challenges

With the accelerated construction of solar PV panels, there is less land available for solar power projects and solar is beginning to compete with agriculture and other industries. To overcome the limited land size, Japan has shifted its focus on rooftop solar. It plans to increase solar power prices on corporate building rooftops from fiscal 2024 to stimulate renewable energy investment. The plan proposes 12 yen per kWh, 20-30% higher than open land solar power rates (Nikkei Asia, 2023). In addition, it has started to develop floating solar systems. Led by SolarDuck, Tokyu Land, and Everblue, Japan would complete its first offshore solar farm with 88kW capacity by 2024. Generated electricity will be transported by autonomous vessels for urban consumption (Lee, 2022).

In the realm of energy storage, Japan's supply chain vulnerabilities become apparent, notably stemming from the concentration of essential mineral reserves and manufacturing capacities in specific global regions. In the context of lithium-ion batteries, the dominating storage technology, crucial raw materials like lithium and cobalt, and manufacturing capacity, are highly concentrated in a few countries (Zissler, 2023). This poses substantial concerns regarding energy security.

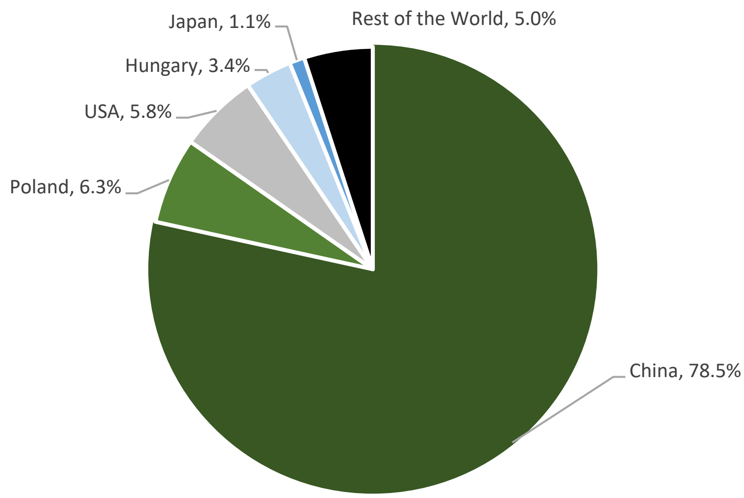

Figure 5.8.1: Lithium-Ion Battery Manufacturing Capacity by Country in 2022 (%) (Zissler, 2023)

In order to secure manufacturing infrastructure for materials and cells, the regulatory bodies have set quantifiable targets to spur the development of battery manufacturing both locally and globally. Japan's 2022 Battery Industry Strategy aims to increase domestic battery and battery material manufacturing capacity to 150 GWh, while globally targeting 600 GWh annually by 2030 (Zissler, 2023). To achieve these goals, the government intends to invest a total of 3.4 trillion in public-private partnerships to provide financial support. This includes permitting the Japan Oil, Gas, and Metals National Corporation to provide up to 75% of the funding for vital raw material procurement initiatives (Zissler, 2023). In addition, emphasis would be placed on strengthening international collaboration, cultivating a skilled workforce, and attaining significant recycling rates for lithium and cobalt, all of which contribute to the sustainable production of batteries.

5.8.4. Energy Storage Solutions

Japan's stationary battery market is set to surge from ¥1 trillion in 2019 to ¥7 trillion by 2030, a 16-fold increase. A prime example of this growth is the GS Yuasa-Kit Toyotomi Substation project, Japan's largest

ESS, featuring a 240,000 kW lithium-ion battery system with a 720,000 kWh capacity (Power Technology, 2023).

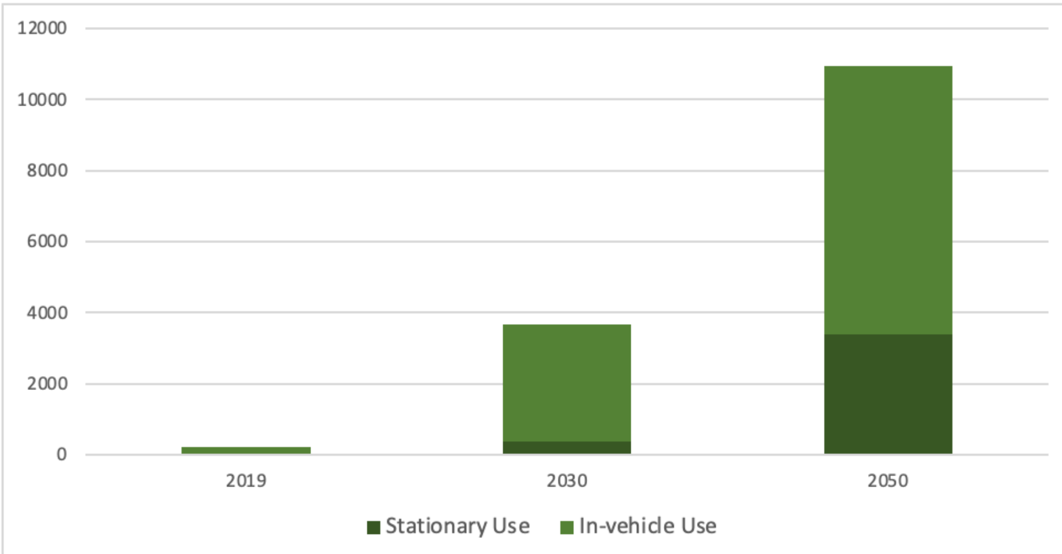

Figure 5.8.2: Stationary Use and In-vehicle Battery Market Size (GWh) (Kidmo et al., 2020)

The Japanese government has taken proactive steps to promote battery storage adoption. Power utilities are required to make their infrastructure accessible to externally operated ESS. Moreover, the government provides subsidies covering as much as 50% of the cost of battery storage systems, which seek to increase the cost competitiveness of battery storage solutions relative to other energy storage methods (EBUCHI, 2022). Specifically, the cabinet aims to reduce the cost of industrial-grade stationary batteries to one-fourth by 2021 from the level of 240,000 yen ($2,100) per kilowatt-hour in fiscal 2019 (TSUGE, 2022). Moreover, Japan transitioned from 20-year flat subsidies to premiums in April 2022, spurring battery investment by creating opportunities for price arbitrage in the electricity market (Zissler, 2023). In addition, a vanadium redox flow battery's lifespan in Japan could potentially extend to 200,000 cycles, greatly exceeding the industry standard of 10,000 cycles (Hu et al., 2017).

Furthermore, Japan has initiated its inaugural commercial utility-scale BESS project this year. These projects, featuring 2 MW capacity and a 4-hour duration, were granted government subsidies in 2021 and have now commenced commercial operations (Colthorpe, 2023). This development, which enables energy trading and participation in power markets, represents a significant milestone in Japan's pursuance of renewable energy development.

5.9. Indonesia

5.9.1 Overview

Indonesia is an equatorial archipelago nation with year-round sunshine. The nation's unique combination of latitude, longitude, geographic diversity, seasonal changes, and temperature allows a consistently high amount of solar radiation to enter the atmosphere (Kabir et al., 2017). Indonesia also enjoys cost-competitiveness of battery productions and it can produce batteries for up to 8% less than China with its abundant nickel-cobalt reserves, low labour costs, and affordable electricity (Bloomberg, 2020). As a result, the nation holds vast potential for renewable energy.

From the current level of a renewable mix of 10%, Indonesia has set goals to more than quadruple and reach 23% of renewable energy in the whole mix by 2025 and attain net zero emissions by 2060 (Zhu & Wijaya, 2023). In terms of solar energy, Indonesia has a significant potential to produce a capacity of more than 207 GW (Tambunan, 2020). The country also intends to contribute to the production of green hydrogen, targeting a generation capacity of 328 MW between 2031 and 2035 (Hydrogen Indonesia, 2022).

Through government-led renewable energy initiatives, the country had successfully installed 12,736.7 MW in EBT electricity Plants (PLT), including 322.6 MW from solar electricity as of the first half of 2023(Chandak, 2023). Regarding power grid infrastructure, the government plans to expand renewable energy integration and increase its capacity for variable power from renewable sources from 5 GW to 28 GW (Chandak, 2023).

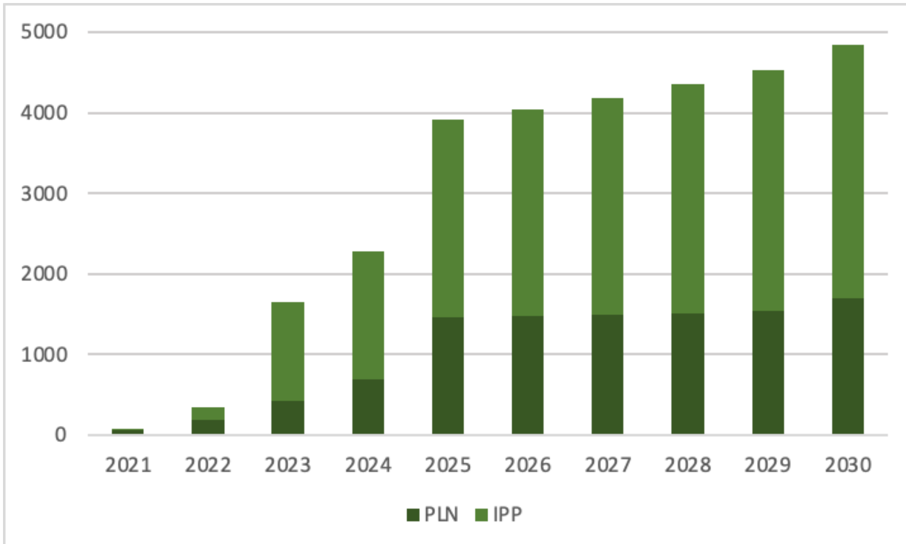

Figure 5.9.1: Solar Capacity Addition Plan in RUPTL 2021-2030 (Bagaskara et al., 2022)

However, despite incentives and regulations, solar energy generation has progressed more slowly than expected. Indonesia's solar deployment has only reached 0.2 GWp* by Q3 2022, with a contribution of power output of less than 1% (Bagaskara et al., 2022). Potential hindrances to solar expansion include delays in planned capacity additions, a lack of solar auctions, and a preference for partnering with regulators over open auctions in floating solar projects (Bagaskara et al., 2022). As a result, the achievement of the 23% renewable energy target by 2025 is at risk.

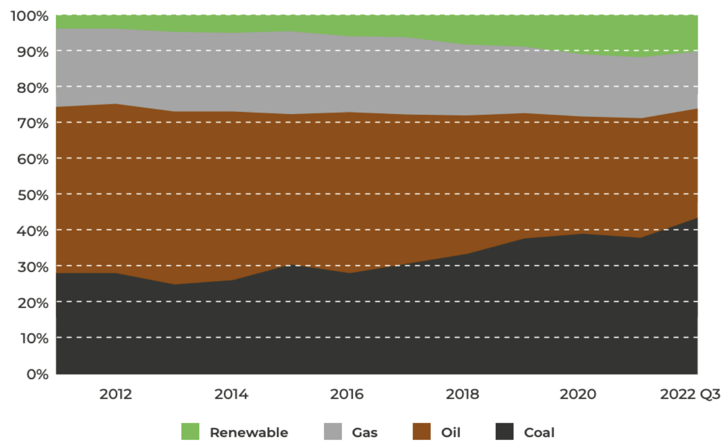

Figure 5.9.2: Indonesia Primary Energy Mix 2011-2022 (Bagaskara et al., 2022)

5.9.2 Regulatory development

In Indonesia, the Ministry of Energy and Mineral Resources (MEMR) is the major regulatory body in charge of developing and enforcing regulations for renewable energy. On the other hand, Indonesia's electricity market is fully controlled by state-owned National Electricity Company (PLN). It has full powers over transmission, distribution, and supply of electricity.

Specific to solar power, Indonesia is temporarily loosening rules that are impeding its growth, enabling solar projects to use imported supplies up until 2025. This action is intended to hasten the nation's switch to cleaner energy sources and is consistent with its goal of achieving net-zero emissions by 2050. This shift is a component of a bigger agenda for policy reform from the draft investment plan for the $20 billion Just Energy Transition Partnership (JETP), an initiative sponsored by President Jokowi in partnership with US President Joe Biden and other developed nations (The Straits Times, 2023).

To incentivise investment in renewables, the government adopts several measures including tax holidays, tax allowance, and import duty facilities. Investors may enjoy a corporate income tax cut up to 100% for 5-20 years based on investment amount (Asia Development Bank, 2020).

However, there is an absence of specific regulatory frameworks for energy storage.

5.9.3 Challenges

Despite established targets for the development of renewable energy, the slow policy and regulatory improvements has led to stagnant investment growth. This problem has been significantly exacerbated by delays in the stipulation of the New and Renewable Energy Bill and the Presidential regulation on renewable energy tariffs (Bagaskara et al., 2022). Investments in renewable energy were just under 35% of the objective as of Q3 2022, totalling USD 3.97 billion (Bagaskara et al., 2022). This has resulted in the slow expansions of both renewable energy sources and batteries. The recent adoption of Presidential Regulation (PR) 112/2022 has been crucial in promoting investment in solar energy. It provided clarity on the procurement process and the electricity purchase price mechanism for renewable power plant projects (IESR, 2021), which could potentially encourage investors to participate in solar power investment.

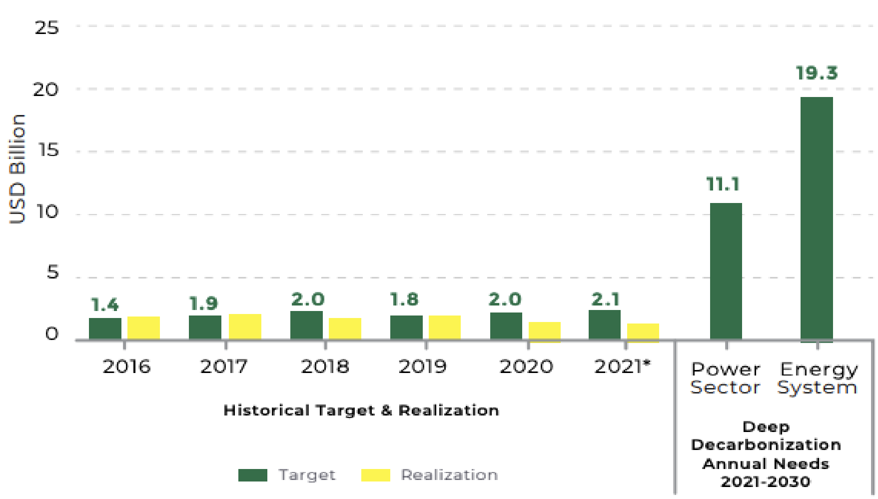

Figure 5.9.3: Energy Sector Investment Realisation vs Target (Tampubolon et al., 2021)

The investment in grid-connected PV systems has also been significantly hampered by the lack of government incentives. Potential investors are deterred from investing in these projects due to the lengthy 17.6-year duration needed for a return on investment (Tarigan et al., 2015). Indonesia has implemented a FiT policy to create a higher selling price of electricity produced by solar PV, encouraging the development of solar power. These tariffs are established using PLN's marginal production costs for power and include a predetermined return rate for investors (Hasan & Wahjosudibjo, 2014). These financial incentives for solar energy production are crucial in luring solar power investments and have been effective in spurring the growth of distributed grid-connected PV systems.

5.9.4 Energy Storage Solutions

With its extensive archipelago of more than 13,000 islands, Indonesia faces unique difficulties in the design, development, and administration of power networks. Due to geographic constraints, a seamless linkage of every large power network to a single national grid is not feasible. Off-grid systems with BESS are being used as a solution to this problem. These BESS applications use solar energy to give rural places a dependable 24/7 electrical supply (Tampubolon et al., 2021).

Additionally, BESS development is accelerated by international partnerships. Notably, private businesses inked three agreements in October 2021 to export solar energy from Indonesia's Riau Islands to Singapore. The agreements aim to provide electricity from 8.67 GW solar power coupled with 12 GWh BESS to Singapore (Tampubolon et al., 2021). Such collaborations are encouraging a wider deployment of battery storage technologies throughout Indonesia's energy sector.

Lastly, due to the high expense of producing electricity from Li-ion batteries for utility-scale solar PV, the authority would begin to examine redox-based batteries made of vanadium or cerium (13 cent per kWh for lithium, while only USD 3.5 cent per kWh for redox).

5.10 China

5.10.1 Overview

China is the world's largest power generator. Its renewable energy sector is undergoing rapid growth. President Xi is committed to achieve carbon neutrality before 2060 (Climate Action Tracker, 2023). In 2021, China has set an ambitious goal for renewable capacity, which includes wind, solar, hydro and nuclear energy, to exceed fossil fuel capacity by 2025 (Wu, 2022). So far, they have marked an early achievement of this target: as of June 2023, China's non-fossil fuel energy sources make up 50.9% of the country's power capacity (Reuters, 2023). In the first half of this year, the country's installed capacity of renewable energy has surpassed 1.32 billion kilowatts.

The growth is especially strong in solar and wind production capacity. According to a report by Global Energy Monitor, China is set to double its capacity and produce 1200 GW of energy through wind and solar power by 2025, reaching its 2023 goal ahead of time. As of 2023 Q1, China's utility-scale solar capacity has reached 228GW, more than the rest of the world combined (Hawkins & Cheung, 2023). Bloomberg forecast on China's solar capacity this year has risen from the previous estimate of 129GW to 154GW (Bloomberg News, 2023). Beside solar energy, the stride in wind capacity is also huge, with combined onshore and offshore capacity as of June 2023 surpassing 310GW, twice of 2017 level and at similar level as the next top seven countries combined (Hawkins & Cheung, 2023). It is expected to add another 371 GW of wind capacity before 2025, increasing the global wind fleet by about half (Hawkins & Cheung, 2023).

However, it is interesting to note that installed thermal capacity still takes up more than half of the total installed capacity as of April 2023, reaching 1,345 GW, 51% of the share of installed capacity (Dong et al., 2023).

		Apr-23	Share of Capacity	Change (yoy %)	Apr-22
Thermal Power	GW	1,345	51%	3.4%	1,300
Hydro Power	GW	416	16%	5.3%	396
Nuclear Power	GW	57	2%	4.3%	54
Wind Power	GW	380	14%	12.2%	338
Solar Power	GW	441	17%	36.6%	323
Total of Installed Capacity	**GW**	**2,649**	**100%**	**9.8%**	**2,412**
Renewable Energy Capacity	GW	1,236	47%	17.0%	1,056
Zero Emissions Capacity	GW	1,304	49%	17.3%	1,112

Figure 5.10.1: China National Installed Capacity as of April 2023 (National Bureau of Statistics of China, 2023)

Technological advancement serves as one main driver for China's energy capacity expansions. One prime initiative would be offshore floating solar panels, where solar panels are installed at a distance from shores. China has successfully built solar farms in the Yellow Sea, around 30 kilometres off the coast. While systems made to resist 10-metre swells may take up to three years to be refined in China, with continued research and investment, ocean-based solar panels capable of managing waves up to 4 metres might become commercially viable within a year (Bloomberg, 2023). However, the harsh marine environment's implications for the reliability of components and devices remains one specific problem to be addressed (Jiang et al., 2023).

Figure 5.10.2: China's Floating Solar Power Platform at Bohai Bay (Xu, 2023)

Apart from leading the renewables production, China is also the leader in energy storage market, with favorable policies and an open window for foreign investors (Wu, 2022). Haitong Securities expects China to have a total renewable energy storage capacity of 97 GW, with with a 49.3% compound annual growth rate from 2023 to 2027, citing data from China Energy Storage Alliance (CNESA) (Haitong Securities, 2023).

5.10.2 Policy and Regulatory development

China has been investing heavily in renewable energy space and contributed to more than 90% of the global increase in energy investment since 2021 (Dong et al., 2023). These investments are used in in ramping up renewables production capacity, building large wind, solar and hydro plants, and giving out financial incentives to meet a target of peak carbon emissions before 2030 (IEA, 2023).

Over the past decade, the government has been giving generous incentives in the renewable energy sector to boost private sector participation, such as FiTs for various renewable energy sources, wind and solar subsidies, tax incentives including reduced income tax and value-added tax rates for renewable energy companies and projects, and electrical vehicle incentives (China Dialogue, 2022).

On the regulatory side, the government implemented various policies to develop the renewables market. FiT for solar and wind energy has been a key policy in China's financial framework to promote renewable energy (Song et al., 2023). Although China ended FiT for solar and wind projects in 2021, as projects became increasingly cost-competitive with other energy sources, it still serves as a great case study for other countries to learn from. Implementation wise, the national price regulator NDRC set different FIT rates for varied renewable projects, which reflect different costs to tap into these resources (China Dialogue, 2022). The pricing formula is a cost-based model, considering the regional average project cost and a fixed internal rate of return (IRR) at usually 8% (China Dialogue, 2022). Price signals sent via FiT policies have provided stable returns for renewable energy projects, driving long-term growth for China's renewable energy market (Song et al., 2023), serving as a major driver behind the early take-off of renewables installations.

Additionally, it introduced Renewable Portfolio Standards in 2019, which requires some provinces and cities to source a certain percentage of energy from renewables, which serves to create a demand for renewable energy (Bu & Zhang, 2020). In a joint statement posted in May 2022, the authorities allowed energy companies to buy and sell electricity directly in China's power markets, opening doors for more profitable energy storage investment (China Briefing, 2022). The authorities also called for provincial authorities to create price mechanisms that can entice power companies to participate in the market (China Briefing, 2022).

Furthermore, China has been welcoming foreign investors in the field of renewables. According to current effective Catalogue of Industries for Encouraging Foreign Investment 2020 Version and the proposed 2022 draft, foreign investors are generally not restricted to access this sector while R&D and application of large energy-storage technologies are especially encouraged for foreign investment (Zhou, 2022). Moreover, the government is also actively promoting international cooperation through joint R&D, standards setting, and infrastructure construction.

Most recently, in 2022, China has established specific targets and roadmaps for renewable energy development via the 14th “Five-Year Plan” on Modern Energy System and Renewable Energy Development respectively (Jing, et al., 2022). The Plan emphasises the link between China’s climate commitments, energy transition, and energy supply security; establishes detailed targets for primary energy mix, power generation rate, electrification rate, and more; and represents a shift from the previous focus in the 13th FYP on air pollution control (Zhou, et al., 2022). Achieving the targets can reduce up to 2.6 gigatons of carbon emissions annually, equivalent to almost a quarter of China’s total carbon emissions in 2020 (Zhou, et al. 2022).

Apart from setting targets, the plans highlight the following key implementation actions: 1) Increase solar and wind power generation in China’s renewable-abundant West and distributed generation for local consumption along the East Coast; 2) Expand off-shore wind; 3) Develop energy storage of big hydro systems; 4) Optimise renewable layout in different regions, and establish new technologies and business models; 5) Integrate renewable centres and microgrids in rural areas for poverty alleviation and rural revitalization (Zhou, et al., 2022).

5.10.3 Key Challenges

Although China's renewable sector has seen substantial growth, the blistering pace of plant installation has not been matching up with the usage capacity, which has led to a significant portion of renewable energy produced being wasted (Wu, 2022). Almost 12% of power generated by wind turbines in Inner Mongolia in 2022 was wasted because the grid could not absorb it, along with 10% of solar power in Qinghai (Economic Information Daily, 2022). In sunny and windswept but sparsely populated Gansu province, the utilization rate of wind and solar power could drop below 90% this year from nearly 97% in 2021 (Bloomberg News, 2022).

Another major challenge along the energy transition journey is the grid inflexibility in transferring energy. The Kela plant is located in the sparsely populated west side of China, where more than three-quarters of coal, wind and solar power is generated. However, the majority of energy consumption is located in the east side. Transporting energy thousands of miles across the country results in inefficiencies (Hawkins & Cheung, 2023). Outdated electricity grid added to the uncertainty in power supply especially during extreme weather. In recent years, record heatwaves and drought crippled hydropower stations, resulting in power crunches that brought factories to a halt (Reuters, 2022).

In addition, although some renewable technologies in China are mature, most are not yet commercially competitive. For example, despite an over 40% decline over the past years, the cost of offshore wind remains more than double that of onshore wind. Others, such as CCUS and green hydrogen, are still in development stages (Xu, 2023).

Furthermore, policy uncertainties in renewable energy might undermine investor confidence and insufficient economic incentives may crowd out private sector participation. There are still many loopholes during the implementation of China's renewables subsidy policies, such as fragmented and uncertain institutional policies, lack of procedural regulations and delayed subsidy fundings (Song et al., 2022).

5.10.4 Energy Storage Solutions

Most investments on ESS have been concentrated on batteries and the government has set the tone to support all forms of batteries, including sodium-ion, novel lithium-ion, lead-carbon, and redox flow. Overall, the installed capacity of renewable energy storage (mostly in the form of batteries) reached 12 GW as of May 2023 (Hayley, 2023). Lithium-ion BESS in China is widely deployed and highly commercialised, which led to significant cost reduction and performance improvements (Bian, 2023).

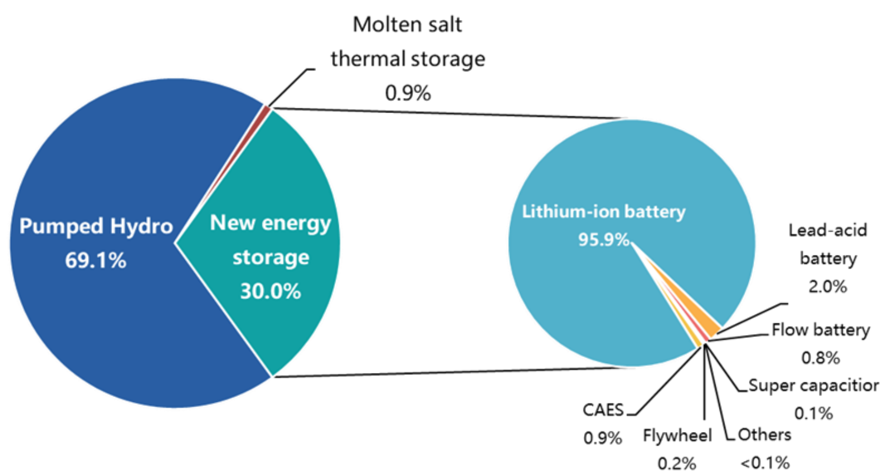

Figure 5.10.3: Cumulative Installed Capacity (MW%) of Electric Energy Storage Projects Commissioned in China as of June 2023 (China Energy Storage Alliance, 2023)

On the policy front, the integration of ESS and renewable energy such as solar PV and wind was given priority. Development of ESS in distributed microgrids and distribution and transmission was also given attention. The government has been exploring cost recovery mechanisms to support the development of stationary energy storage powered by wind and solar energy, by incorporating electrochemical and compressed-air energy storage into ancillary services in the power market (NEA, 2021). Establishing connection between stationary energy storage projects and the power market helps to reduce financing burden on power grid companies (Bian, 2023).

Building upon those developments, China's 14th Five-Year-Plan 2022 for Energy Storage calls for a wider ecosystem of government and private entities to build the energy storage sector and emphasises the role of market forces, including generation utilities and independent service providers, in investing in storage projects (NDRC & NEA, 2022). More specifically, the plan outlines collective development of various new energy storage technologies, including compressed air, hydrogen, battery, and thermal energy, aiming to be self-sufficient in the key areas of renewables storage (Wu, 2023). It also sets out ambitious targets for the development of 30GW from non-pumped hydro energy storage technologies as well as their commercialization and large-scale implementation by 2030. Following the plan, more than 20 provinces have announced plans to install ESS over the past year, with combined capacity over 40 GW (Wu, 2023).

This year, to avoid power outages that heavily affected the nation last year, China is trying to improve flexible power transmission in its grid system. Facing decreased output from hydropower plants, the government has rationally optimised power transmission between provinces to send more power to the drought-stricken southwest (Hayley, 2023).

5.11 South Korea

5.11.1 Overview

Electricity demand in Korea is forecasted to increase by 31% by 2035 and 113% by 2050 compared to 2020 levels (Park et al., 2023). This year, the new president Yoon Suk-yeol has revised Korea's emission target. The country's total reduction target kept unchanged at 40% of 2018 levels and plans to secure spaces to capture and store 1 billion mt of CO2 by 2030 (Yep & Lee, 2023). However, as of 2022, electricity generation was still heavily reliant on coal and LNG and less than 10% was generated from renewables (Statista, 2023).

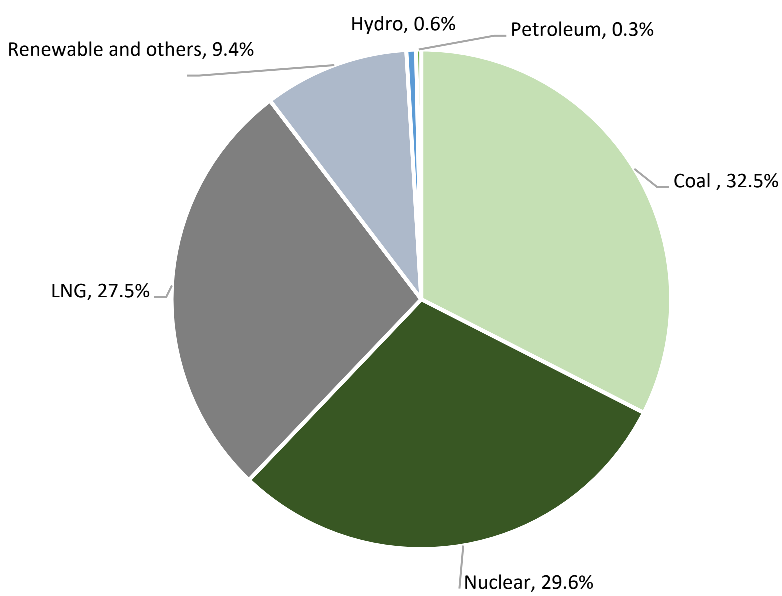

Figure 5.11.1: Distribution of Power Generation in South Korea in 2022 (Statista, 2023)

The government has been committed to increasing renewable energy supply in the energy mix and developing its nascent hydrogen industry, with priority being energy security. In July 2020, they passed a Green New Deal as part of the pandemic recovery package, which was a remarkable move for green energy transition (IEA, 2020). They have set a goal of net-zero by 2050 and cutting greenhouse gas emission by 40% by 2030 (Tachev, 2023).

However, looking at the current energy mix, the country is likely to be still reliant on fossil fuel by 2030. Without robust plans and concrete short-term milestones, the country faces high risk of not reaching its emission targets (Tachev, 2023).

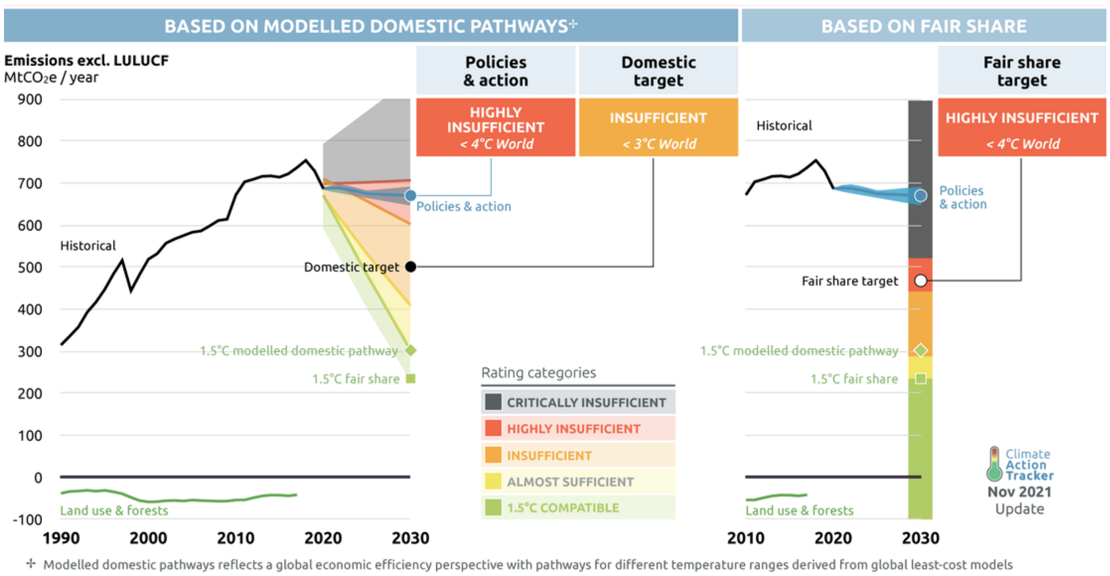

Figure 5.11.2: South Korea's Overall Rating Being Highly Insufficient (Climate Action Tracker, 2023)

Most of the renewable energy in Korea is in the form of solar energy. With cutting-edge technology, it has become the only country to compete with China in high efficiency-based advanced solar energy market (Lee, 2022). It has successfully developed Perovskite solar cell material in 2021 and broke the record efficiency of 25.2%. Korea is investing heavily to develop tandem solar cell technology targeting above 30% efficiency (Lee, 2022).

5.11.2 Policies and Regulatory Development

Back in 2020, Korea has launched the 5th Basic Plan on Renewable Energy, with a goal to move into the low-carbon economy and deploy 84.4 GW renewable energy facilities by 2034 to create the ecosystem incorporating renewable energy as main power source (Lee, 2022). Ultimately, the country is aiming to have renewable energy account for 25.8% of total energy mix by taking a long-run strategic view (Climate Policy Database, 2022).

Figure 5.11.3: South Korea 5th Basic Plan on Renewable Energy - December 2020 (Lee, 2022)

Earlier this year, South Korea's Ministry of Trade, Industry and Energy (MOTIE) finalised the bulk of its 10th Basic Energy Plan (Tachev, 2023). One of the highlights in the Plan is to prioritise a shift back to nuclear energy (World Nuclear News, 2023). This removes former President Moon Jae-in's policy, which was implemented after Japan's 2011 Fukushima Daiichi accident (World Nuclear News, 2023). MOTIE listed a few priorities in the plan, including developing a stable electricity supply for energy security, achieving a more balanced energy mix, focusing on coal and ammonia co-firing and blue hydrogen to reduce emissions, accommodating renewable energy storage through an investment of about USD 36 billion and expanding the grid (Tachev, 2023).

Another key initiative the government has been implementing since 2019 is the global RE100 (Renewable Electricity 100%) - a volunteer campaign promoting using renewable energy to produce electricity in the private sector, led by the Carbon Disclosure Project under the leadership of MOTIE (RE100, 2023). It has encouraged implementation of the Korean-style RE100 for domestic companies by way of renewable energy procurement including green premium, Renewable Energy Certificate purchase, third party Power Purchase Agreement, and self-generation (Lee, 2022). Due to the high dependency of industries on trade, RE100 implementation has been seen as a necessity rather than an option for companies. As of May 2022, more than 369 companies volunteered to participate in the campaign. The number of participating companies are on the rise year after year (Lee, 2022).

5.11.3. Key Challenges

Despite the government's efforts to develop RE, Korea's current power system reliability and electricity maintenance standards do not address system inertia issue (Park et al., 2023). System inertia is a measure of a power system's ability to resist frequency disturbances. Lack of system inertia can lead to unreliable frequency in power supply and cause generators to trip, leading to power outages (Linaro et al., 2023).

Congestion and delays in grid interconnection pose another challenge. In Korea, regions with abundant renewable energy resources and the areas with high electricity demand are far apart. Existing transmission capacity is limited, which can lead to severe congestion on the transmission system without significant reinforcement (Park et al., 2023). In Korea, delays in grid interconnection are common, and most of them are due to bottlenecks in planning and implementation processes, rather than technical difficulties (Noorfatima, 2021).

Furthermore, high costs is a key barrier for renewable energy deployment in Korea. High costs are mainly due to expenses related to land, financing, and corporate taxes. Korea's levelized cost of energy for renewable energy is only second to Japan. Lack of Korean tax incentives, combined with high capital expenditure requirements, multi-criteria procurement auctions, renewable energy certificate surpluses, and mandates for local sourcing of materials and components can severely affect the economic feasibility of renewable energy systems (Park et al.,2023).

5.11.4. Energy Storage Solutions

The development of South Korea's ESS was primarily driven by the 5th Renewable Energy Plan. Increasing transmission deferral projects by KEPCO and MOITE, renewable energy targets, growing demand for rooftop solar solutions, and energy security issues all contribute to the rising demand for energy storage market over the past years (World Bank Group, 2020). South Korea deploys various energy storage solutions, including mainly pumped hydro and electrochemical batteries.

With rivers flowing west and south, South Korea has leveraged on its geographical advantage to build hydro power ESS. In 2021, the capacity was 1789 MW of pure hydropower and another 4700MW of pumped storage (BlackRidge, 2023). However, most hydropower plants were built 40-50 years ago, and require maintenance and modernising work to improve performance. The government is also undertaking new pumped storage power plant projects, for example, Korea Hydro and Nuclear Power, where the government plans to complete construction in 2031 (BlackRidge, 2023).

On top of pumped hydro, lithium-ion battery ESS has also seen remarkable growth in Korea in recent years, with conglomerate Korean companies like LG Chem, Samsung SDI and SK Group accounting for more than 80% of total lithium-ion battery ESS market (BlackRidge, 2023). One key development took place in 2018, where New Renewable Portfolio standards and FiTs for solar rooftops boosted demand for ESS in industries, commercial and residential buildings (Kwon, 2020). The strong battery manufacturing base has been a solid support for battery ESS in Korea, and most lithium-ion battery ESS built in the last 10 years. Companies and governments are supporting R&D on batteries to improve performance, efficiency, safety and output. Most recently, in August 2023, South Korea launched a competitive solicitation for large-scale ESS on Jeju Island (Colthrope, 2023). This project is expected to open up a “central contract market” for battery energy storage.

6. Synthesis of Literature Review

6.1 Governance and Policy Making

Countries	Short and long-term objectives	Objectives are quantifiable and achievable	Players Involved
Singapore	• **Short-term:** Singapore plans to deploy 2 GWp of solar energy by 2030 which would account for 3% of total energy demand To accommodate this, Singapore planned to add 200 MW of ESS by 2025 • **Long-term:** Singapore has also pledged their commitment to net-zero by 2050	• Objectives are quantifiable and achievable • Frameworks and plans put in place look robust and provide assurance that targets will be met	• Energy Market Authority (EMA) • Ministry of Sustainability and the Environment (MSE)
Thailand	• **Short term:** National Energy Plan (2018-2037) was developed to help achieve targets • **Long term:** Thailand has affirmed their commitment for renewable energy to make up at least 30% of power generating capacity by 2037	• Objectives are quantifiable and achievable as the Thai government has developed The National Energy Plan, or NEP (2018-2037) • However, the fragmented authoritative structure has led to inefficient planning and multiple revisions of the NEP as policies keep changing	• Ministry of Energy (MOE) • National Energy Policy Council (NEPC) • Energy Policy and Planning Office (EPPO) • Energy Regulation Commission (ERC)

			• Electricity Generating Authority of Thailand (EGAT)
Vietnam	• **Short-term:** In its Solar Power Development Plan, Vietnam aims to build rooftop solar panels on 50% of office and residential buildings by the end of the decade. Wind, solar, hydropower, and biomass will make up 48% of Vietnam's installed capacity by 2030 • **Long-term**: Wind, solar, hydropower, and biomass will make up 63% of Vietnam's installed capacity by 2050	• Objectives are quantifiable and achievable • However, there hasn't been any regulatory advancement made specifically for the implementation of ESS	• Ministry of Industry and Trade of Vietnam (MOIT) • Electricity and Renewable Energy Authority in Viet Nam (EREA)
India	• **Short-term:** India has an ambitious goal of increasing its solar capacity by six times, to 450 GW, by 2030. It has launched the national energy storage mission, with a robust target of 40 GW storage capacity by 2025	• Objectives are quantifiable, with a target of 40 GW storage capacity by 2025. • Key policy barriers currently include a lack of provision for storage energy policies and targeted support for early	• Ministry of New and Renewable Energy • National Institution for Transforming India (NITI) Aayog

	• **Long-term:** India aims to increase the capacity of solar-based energy to 1,689 GW by 2050 and 5,630 GW by 2070	adopters of storage technologies.	
Australia	• **Short-term:** NA • **Long-term:** Australia aims to generate 82% of their power from renewable energy by 2030 (up from 35.9% in 2023)	• Australia is of the most developed countries in renewable energy generation and have achieved most of their previous targets • Targets are quantifiable but not achievable. There is criticism regarding their goal of achieving 82% of renewable energy generation by 2030	• Australian Energy Market Operator (AEMO) • Australian Energy Market Commission (AEMC)
Malaysia	• **Short-term:** The government's targets of achieving 31% renewable capacity by 2025 • **Long-term:** Target to achieve 40% renewable capacity by 2035	• Targets are quantifiable • Targets are not achievable due to lack of detailed policy, clear roadmap and strict implementation measures	• Economic Planning Unit (EPU) of the Prime Minister's Department • Ministry of Energy, Green Technology, and Water • Energy Commission
Philippines	• **Short-term:** NA • **Long-term:** Aligned with its National Renewable Energy	• Targets are quantifiable • Investor perception of unclear government signals and	• National Power Corporation

	Program (NREP) 2020-2040, the Philippines aims to have renewables contribute 35% of power generation by 2030 and 50% by 2040	policies is evident, which restrains the country from achieving the goals	• Energy Regulatory Commission (ERC) • National Grid Corporation of the Philippines (NGCP)
New Zealand	• **Short-term:** New Zealand has short-term objectives such as leveraging DER to build and operate the future grid, balancing renewable generation to be achieved in 3 - 7 years • **Long-term:** The government has set ambitious targets, including achieving 100% renewable energy generation by 2030 and net-zero emissions by 2050	• Targets are quantifiable and achievable • The NZ Battery Project is an initiative that will offer thorough guidance on the commercial, technical, and environmental viability of various energy storage facilities. The project's feasibility studies are anticipated to be finished in 2023, and solutions should be in place by the 2030s	• Minister of Energy and Resources • Ministry of Business, Innovation and Employment (MBIE) • Commerce Commission • Electricity Authority
Japan	• **Short-term:** Its renewable power generation target increased to 36%-38% and its solar power capacity target rose to 108GW by 2030 • **Long-term:** It aims to achieve carbon neutrality by 2050	• Both renewable energy generation and storage objectives are quantifiable and achievable. Japan has aimed to construct 3 to 4 gigawatts of battery storage capacity by 2030	• Ministry of Economy • Trade and Industry(MEIT) • The Japanese Ministry of the Environment

Indonesia	• **Short-term:** Indonesia has set goals to more than quadruple and reach 23% of renewable energy in the whole mix by 2025 • **Long-term:** The country aims to attain net zero emissions by 2060	• Targets are quantifiable • However, goals are unlikely to be achieved given Indonesia's slow progress in renewable energy development	• Ministry of Energy and Mineral Resources (MEMR) • State-owned National Electricity Company(PLN)
China	• **Short-Term:** By 2025, Renewable capacity to exceed fossil fuel capacity (Already achieved in 2023) • **Updated NDC targets by 2030:** ○ Peaking carbon dioxide emissions by 2030 ○ Lower carbon intensity by 65% from the 2005 level ○ Cut share of non-fossil fuels in energy consumption to 25% ○ Increase forest stock volume by around 6 billion cubic metres in 2030 from the 2005 level	• Highly quantifiable, with established targets and roadmaps in 14th "Five-Year Plan (FYP)" • Energy-related NDC targets are achievable, current progress set to overachieve targets • Current policies but are not yet sufficient to ensure China meets its carbon intensity target • Unable to counter growing energy demand and reduce dependence on fossil fuels	• National Energy Administration (NEA) under National Development and Reform Commission (NDRC) • Ministry of Commerce • Chinese Renewable Energy Industries Association (CREIA) • State Grid Corporation of China • Sinohydro

	o Increase the installed capacity of wind and solar power to over 1,200 GW • **Long-Term:** Achieve carbon neutrality by 2060		
South Korea	• **Short-Term:** Share of coal in power production lowered to 19.7% by 2030; LNG's share in power cut to 22.9% in 2030; Renewable sources responsible for 21.6% of power generation by 2030 • **Long-Term:** Renewable sources responsible for 30.6% of power generation by 2036; LNG's share in power cut to just 9.3% in 2036	• Highly quantifiable but largely not achievable • Looking at the current energy mix, the country is likely to be still reliant on fossil fuel by 2030 • Lack of robust roadmap to reduce reliance on fossil fuel	• Ministry of Trade, Industry and Energy (MOTIE) • Korea Electric Power Corporation (KEPCO)

Table 6.1.1: Overview of Renewable Energy Governance and Policy Development in APAC

6.2 Financial Incentives

Countries	Subsidies to R&D	Subsidies to Implementation	Policy incentives for investors
Singapore	• EMA provides grants to catalyse R&D of innovative technologies and solutions. Examples include R&D grants for solar, ESS, smart grid and other renewable energy	• No subsidies for private sector to promote renewable energy but has taken proactive steps to introduce regulation when technologies become commercially viable	• No policies, tax incentives or feed-in tariffs for renewable energy projects or investments
Thailand	• Thailand provides subsidies for every step of renewable energy • The ENCON fund is funded by levies on petroleum products. • The fund provides for both R&D programs, implementation and project financing	• Small and very small power producers using renewable energy are eligible for a FiT on top of the wholesale electricity price	• The Thai government also supports renewable energy investment projects through (BOI) • Incentives to encourage investment in renewable energy-related projects as well as to incentivize individual companies to invest in generating electricity through renewable means
Vietnam	• Subsidies for renewable energy R&D is lacking	• The VEPF provides subsidies for renewable electricity produced from solar when	• FIT3 can potentially be implemented at a lower price of $5.2 to $5.8 US cents/kWh.

		production costs are more than the sale price	• Corporate income tax and import tax benefits are available for projects in Vietnam that involve the development of renewable energy sources.
India	• Subsidies for renewable energy R&D is lacking	• India plans to offer businesses establishing 4,000 MWh of battery storage facilities subsidies amounting to 37.6 billion rupees ($455.2 million) and intends to provide substantial subsidies totaling $2.5 billion to large-scale battery manufacturers	• There is generally a lack of accessible, flexible financing options and tax exemptions in renewable energy
Australia	• Generous subsidies for R&D • R&D tax Incentive (RDTI) program to support Australian industry-based R&D • National Reconstruction Fund (NRF) to offer funding for projects in a few areas including renewables and low emission technologies	• Substantial funding to transmission projects, e.g. $75 million for Marinus Link project, $250 million for the VNI West project • Emerging Energy Program - $75 million to subsidise energy storage projects	• Lack of clear incentives for investors

Malaysia	• Subsidies for renewable energy R&D is lacking	• Net Energy Metering (NEM) program: consumers can offset their energy consumption with energy generated from their solar panels	• FiTs and tax incentives to encourage solar PV projects investment • The government provides stable and long-term contracts for renewable energy producers
Philippines	• Subsidies for renewable energy R&D is lacking	• Incentives such as a seven-year income tax holiday and FiTs scheme are eligible for renewable energy developers • The government also introduced a net metering system to promote usage of renewable energy	• Foreign investors can now hold 100% equity in the exploration, development, and utilisation of solar, wind, hydro, and ocean or tidal energy resources
New Zealand	• There is no government subsidy for new electricity generation in New Zealand since renewable energy is already cost-competitive in the country	• MBIE established funds for community-based renewable energy projects, including grants for the development costs of projects, and fund implementation costs • This initiative focuses on low-income communities and/or insecure access to energy	• The Emissions Trading Scheme (ETS) requires companies to track and report on their greenhouse gas emissions • EST increases businesses' investments in renewable energy

			projects as they need to follow the government's requirement by reducing the emission unit of their businesses
Japan	• Generous subsidies for R&D • The government would provide two initiatives to expedite R&D and promote the use of hydrogen over the next ten years with up to ¥370 billion ($3.4 billion) from its green innovation fund	• Budget of JPY 300 million for solar power generating projects developed on farms, reservoirs, and garbage disposal sites • Subsidies to promote installation of solar panels on buildings by lowering the initial installation cost • Subsidies for storage battery and chip projects	• In 2022, the ministry has implemented a fixed FiT of ¥ 10 -11/kWh for PV systems depending on their power capacity which will be valid for 20 years
Indonesia	• Subsidies for renewable energy R&D is lacking	• FiT policy to create a higher selling price of electricity produced by solar PV	• Tax holidays, tax allowance, and import duty facilities. • Investors may enjoy a corporate income tax cut up to 100% for 5-20 years based on investment amount.

China	• Generous subsidies for R&D • Various subsidy programs, e.g. National and Provincial Programs to fund for research projects, 863 Program to fund R&D for various sectors including renewable energy, Clean Energy Development Fund to support R&D projects, and • Various government grants for R&D	• FiT to provide guaranteed payments to RE project developers for electricity they generate • Tax incentives • Top Runner Program which encourages deployment of RE technologies by providing additional subsidies	• FiT to provide revenue stability for investors • Tax incentives • Encouraging foreign investment in large energy-storage technologies through Catalogue of Industries for Encouraging Foreign Investment
South Korea	• Generous subsidies for R&D • Korea Institute of Energy Technology Evaluation and Planning offers financial support for R&D projects in RE sector • MOTIE's RE R&D programs providing grants and other support for RE projects • Tax incentives for businesses involving in RE R&D	• Green premium to encourage implementation of the Korean-style RE100 for domestic companies by way of renewable energy procurement • Renewable Portfolio Standards (RPS) • Renewable Energy Certificate (REC) System	• FiT • Tax incentives

Table 6.2.1: Overview of Financial Incentives for Renewable Energy in APAC

6.3 Technology

Countries	Renewable Energy Technology Implemented	Renewable Energy Storage Technology Implemented	New Renewable Energy Technology Under Development
Singapore	• Solar: Floating and rooftop solar panels • Biomass and municipal waste used for energy generation	• Lithium-iron phosphate (LFP) batteries	• R&D for hydrogen fuel cells • Geological study for potential geothermal energy generation
Thailand	• Wind • Hydro • Solar	• NA	• R&D for hydrogen fuel cells
Vietnam	• Hydroelectricity • Wind • Solar • Biomass	• Large-scale BESS with LFP Batteries • Integration of battery storage with rooftop solar PV	• Geothermal energy and tidal energy are at a very early stage
India	• Solar • Wind • Hydro	• Large-scale BESS with LFP Batteries	• Mission on Advanced and High-Impact Research: aim to facilitate indigenous research, development and demonstration of the latest and emerging

			technologies in the power sector
Australia	• Solar: Rooftop solar • Wind • Hydro • Geothermal • Bioenergy • Marine	• Large-scale BESS with LFP Batteries • Rooftop Solar • Virtual Power Plant (VPP) • Smart Metering System • Pumped Hydro	• Sun Cable Project (ongoing development): will be the world's largest solar farm • Concentrated Solar Thermal (CST) Technology: at early stage of development
Malaysia	• Hydro • Solar • Wind	• Large-scale BESS with LFP Batteries	• Pilot projects aimed at improving conversion of biomass into energy • Designating Sarawak as a green hydrogen development hub
Philippines	• Hydro • Solar • Wind	• Large-scale BESS with LFP Batteries	• Virtual synchronous generator (VSG) technology which is designed to juggle large amounts of renewable energy
New Zealand	• Hydro • Geothermal	• Large-scale BESS with LFP Batteries	• The adoption of Distributed Energy

	• Solar		Resources (DER), such as solar PV, EVs, batteries, and smart appliances
Japan	• Solar: Floating and rooftop solar panels • Wind • Geothermal • Hydropower • Biomass	• All-solid-state and Liquid Lithium-ion batteries (researchers have created a safer lithium-ion battery by substituting water for the volatile organic solvent) • Flow battery • Sodium-Sulphur (NaS) Batteries	• Offshore Sea-based Floating solar panels by Q1 2024 • Space-based solar power
Indonesia	• Solar: Floating and rooftop solar panels • Geothermal • Hydropower • Biomass • Wind	• Large-scale BESS with LFP Batteries • Pumped Storage Hydropower • Flow battery • Lead-Acid Batteries	• Green hydrogen production with estimated generation capacity of 328 MW between 2031 and 2035
China	• Hydroelectric power plants (largest component of RE production) • Wind power plants (second largest component of RE production) • Solar	• Large-scale BESS with LFP Batteries	• Expansion of Solar PV: Set to reach over 700 GW by 2024 and increase to close to 900 GW by the end of 2025 • Expansion of Wind and Solar Capacity: Set to

			produce 1,200 gigawatts of energy through wind and solar power by 2025
South Korea	• Hydroelectric power plants • Wind power plants • Solar	• Large-scale BESS with LFP Batteries	• Building-Integrated PV (BIPV) with rebates system • Hydrogen industry is building infrastructure to tap into hydrogen such as hydrogen cars and fuel cells, while adding infrastructure for green hydrogen production

Table 6.3.1: Overview of ESS Technology Development in APAC

6.4 Key Insights from Secondary Research

Based on the literature review, we identified a few best practices across the APAC countries, which Singapore can reference and learn from. We categorised the synthesis of best practices and applicability to Singapore into three major aspects: Governance and Policy Making, Financial Incentives, and Technology.

6.4.1 Governance and Policy Making

In New Zealand, a thorough feasibility study for the NZ Battery Project is conducted before placing solutions in the 2030s. The process consists of 3 parts. It starts with feasibility studies of potential solutions and identifications of options worth further evaluation. The government then designs a detailed business case of selected options and makes final investment decisions. Lastly, preferred options or solutions will be fully implemented by the 2030s. The process of strategy formulation is essential for promoting informed decision-making and ensuring the smooth implementation of long-term sustainable renewable energy initiatives.

Similar to New Zealand, frameworks and targets that are set out by the EMA are clear, realistic and achievable. Singapore was ranked top for government effectiveness in policy making and implementation by the World Bank in 2021 (Ministry of Finance, 2023). Its clear guidelines for sustainable implementations make it possible for stakeholders to execute plans effectively and facilitate straightforward monitoring of progress.

Japan, on the other hand, has successfully used a top-down, centralised strategy to address the technical, environmental, and business aspect of developing battery storage systems. Japan is concentrating its technological efforts on developing and improving battery production technologies to compete globally. In order to expand its market, the nation is aggressively supporting the development of all-solid-state batteries, which are thought to be next-generation technology, through joint efforts between the government, business, and academic community. The goal is to reach full-scale commercialization by 2030 to tackle intensified global competitiveness. To encourage battery storage investments from developers, the government implemented RE feed-in premiums, as opposed to the prior 20-year flat subsidies. Furthermore, Japan prioritises environmental concerns, carrying out sustainability studies that include estimating carbon footprints, evaluating and reducing supply chain risks, and promoting reuse and recycling (METI, 2022). This thorough and well-rounded approach contrasts with Thailand which has a fragmented authoritative structure and the nation’s energy policies, planning and implementations are contradictory (Sirasoontorn & Koomsup, 2016).

Like Japan, the EMA is involved in every aspect of renewable energy projects from seeding R&D, selecting private companies to execute renewable energy projects and regulating the industry. This shows Singapore’s well-rounded governance and policy making when it comes to renewable energy. Its multi-faceted planning and decision-making not only guarantees effective policy implementation and execution but also empowers the successful achievement of energy targets.

6.4.2 Financial Incentives

The use of financial incentives can be explored to stimulate the renewable energy and ESS sector in many other countries. Financial incentives can be used into three main segments: renewable energy R&D, renewable energy implementation, and renewable energy investment. One common incentive across many APAC countries is FiTs. In particular, China’s use of FiTs - successes in FiTs have spurred investment into renewable energy projects by providing price certainty and a cost-based compensation. This provides a good model for other countries to learn from.

However, Singapore and New Zealand are the only 2 countries that do not implement FiT for renewable energy. FiTs may not be applicable in this context primarily because FiTs would have to be applied to the whole market, distorting the price of energy and would likely lead to higher energy prices for consumers. The EMA views FiT as an increased cost to consumers and distorts energy markets, sending the wrong price signals to consumers and investors. Furthermore, FiT is a highly costly policy, and Singapore has made great progress in solar energy without the use of FiTs. In Singapore, the gap in solar installation only lies in privately owned buildings and not the entire market. New Zealand, on the other hand, avoids FiTs as the country already has abundant renewable energy and does not need to incentivise uptake and does not want to place upward pressure on electricity prices (Stone, 2013).

Additionally, it was observed that, in countries with successful renewable energy development schemes, governments were generous in providing subsidies, grants and other incentive programs to incentivise private sector participation. Notably, Thailand's ENCON fund provides a successful case study which could be replicated in Singapore's context. It provides fundings for a wide range of solutions such as R&D, working capital, grants and subsidies for investment in energy conservation programs in both public and private sectors. With specific programmatic instruments to target particular beneficiaries, this initiative worked as an effective initiative for Thai development.

On the contrary, Singapore has less developed incentive mechanisms for renewable energy amongst ASEAN countries. The EMA chooses to instead support R&D programs through grants such that renewable energy technologies become economically viable and thus adopted. Where projects are not commercially viable, like in the case of ESS, EMA partners with private companies via the Accelerating Energy Storage for Singapore (ACCESS) Programme. The breakdown of costs of ESS projects between the private company and EMA is not publicly available. Singapore's financial incentives are mainly focused on R&D rather than project subsidies and implementation incentives. Singapore can learn from Thailand ENCON fund to provide funds for a comprehensive range of solutions in RE and establish specific programmatic instruments under each category.

6.4.3 Technology

China has been a global leader in the adoption of floating solar due to the rapid growth in its floating solar industry over the past few years. One notable example is offshore solar farms in the Yellow Sea, around 30 kilometres off the coast. With 95% of energy contributed from fossil fuels, Singapore has the obligation to improve renewable energy generation and floating solar is a viable measure given land scarcity in the country. While Singapore has built a massive floating solar farm at Tengeh Reservoir, offshore floating solar farms is a potential development that could enable Singapore to utilise locations out at sea to provide renewables (Lin, 2021). Offshore space offers opportunities for cities like Singapore with a high population density and limited land to tap solar energy. These areas are exposed to the sun and have low risks of theft or vandalism, which could be considered for Singapore to enhance renewable facilities.

Australia is advanced in renewable energy development and ESS. The country is creating ESS based VPPs models. By improving customer outcomes and supporting local and regional electricity grids, the incorporation of VPP will play a vital role in the transition to renewable energy. This model is an innovative approach to managing and optimising distributed energy resources, including energy storage, in a way that benefits both individual energy system owners and the broader energy grid. VPP is specifically beneficial to Singapore as it could be used to balance energy fluctuations brought by solar intermittency at different sites. While maintaining the stability of the power system, it allows the integration of more distributed and sustainable energy sources, including solar power, into Singapore's energy mix. Residential solar panels and batteries, being an important part of Australia's VPP system, is an excellent example for Singapore to learn. In land-constrained Singapore, rooftops provide the most readily available space for the rollout of solar panels (Bandera & Gorman, n.d.) Moreover, Australia has developing technologies such as Vehicle to Grid (V2G), which is a new form of distributed energy. As EVs are gaining popularity in Singapore, V2G technology has the potential to add to Singapore's energy diversity. Lastly, synergizing with VPP, Australia's smart metering system provides a good reference for other countries. Smart metres provide real-time prices and consumption patterns, whereby households can be incentivised to cut down on usage during peak hour, or even discharge extra energy into the electricity market to earn financial return. This helps increase energy efficiency. Australia serves as a good example whereby smart metering is well incorporated into the electricity market and works in tandem with VPP. Smart metering can be part of Singapore's broader efforts to enhance energy efficiency, reduce energy consumption, and promote sustainability.

Malaysia is a leading country in renewable energy and energy storage development in Southeast Asia. It has developed cutting edge technologies such as recycling of EV batteries. Prominent automakers such as BMW Group Malaysia are assessing the uses of retired EV batteries for energy storage purposes. Recycling could reduce the need for mining and extracting new resources, helping conserve valuable metals and minerals in Singapore. Reusing EV batteries can reduce the cost of the ESS project and improve the environment by lowering battery waste and carbon emissions. Lastly, as Singapore is striving to achieve a circular economy, recycling and reusing EV batteries can help the country reach the goal by reusing resources and minimising waste.

7. Synthesis of Primary Research

7.1 Overview of Singapore's Renewable Energy and ESS Solutions

Singapore's energy landscape remains predominantly reliant on gas and fossil fuels. Although significant efforts have been directed towards the development of renewable energy sources, Singapore's limited wind resources and scarcity of available land have positioned solar energy as the most viable option. Despite its potential, solar energy still constitutes a relatively modest fraction of the overall energy output in the country. Nevertheless, Singapore distinguishes itself with its technological advancements in the renewable energy sector, boasting Technology Readiness Level (TRL) of 6 to 7. This achievement is exemplified by the adoption of highly efficient PV modules and cutting-edge innovations like floating solar panels.

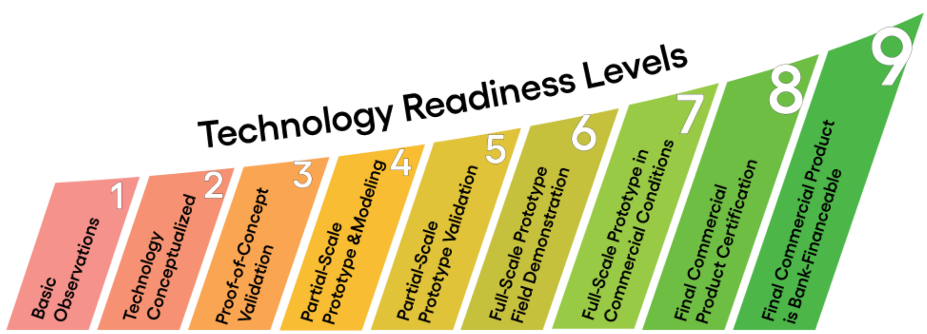

Figure 7.1.1: Technology Readiness Level for Renewable Energy Development

Looking ahead, Singapore possesses the capacity for further expansion of its renewable energy infrastructure, benefiting from a robust and stable power grid, ongoing exploration of battery systems deployment, and favourable over-capacity conditions within the power supply sector. In addition, Singapore is also seen as a trusted market player for investors due to the government's commitment for renewable energy. However, the key challenge lies in the practical deployment of these resources.

7.2 Policies and Regulatory Development

While the government has established revenue support schemes for renewable energy projects, the bidding process is fiercely competitive. Although some banks actively provide financing, their interest is limited when it comes to supporting purely green initiatives lacking commercial or financial viability. For projects such as ESS, constrained by Singapore's limited renewable capacity and growth potential, securing funding becomes highly challenging. To effectively address this issue, it is crucial to enhance government involvement and institute targeted financial incentives to catalyse private sector investments in renewable energy initiatives. For instance, government entities such as GIC and Temasek could play a pivotal role by leading in financing Singapore's ESS projects. Furthermore, the government could establish renewable energy financing targets for banks, encouraging them to prioritise projects that contribute to sustainable impact rather than focusing solely on financial returns.

7.3 Current ESS Solutions and VPPs

Both ESS and VPPs represent indispensable initiatives as Singapore progresses in its pursuit of renewable energy capacity. However, due to the current scale of Singapore's energy storage solutions, their primary role remains mitigating demand-side issues that may result in intermittent energy shortages, often caused by factors like grid congestion.

While Singapore has established a transparent policy and a well-developed legal framework to support such advancements, questions persist regarding the sustainability of storage solutions, primarily due to the limited financing available for battery projects.

7.4 Evaluation for Potential Recommendations

Installing batteries alongside rooftop solar panels appears to be a technically viable solution for the future. Similar projects have been successfully implemented by SKYE Renewables in Australia. Moreover, advancements in rooftop solar technology, such as those developed by companies like Solar AI Technologies, have the potential to significantly enhance the effectiveness of rooftop battery storage. However, its commercial viability faces significant challenges within the current Singapore energy market. Singapore's energy pricing structure, which maintains consistent volume and prices of electricity throughout the day, does not allow for pricing arbitrage and hence represents limited revenue incentive for project operators. Additionally, the initial expenses associated with installing batteries on rooftops can be substantial.

The concept of reusing EV batteries holds promise, especially considering the rapid growth of the EV sector, which is expected to thrive for the next five years. Up to 60% of EV battery capacity can be repurposed for other applications in the industry.

Another potential initiative to enhance the effectiveness of rooftop and EV battery storage involves the installation of smart metre systems. These systems would empower customers to actively participate in energy management, shifting the initiative from investors to consumers. Such an approach could become more commercially viable through the implementation of proper pricing mechanisms. For instance, customers could pay higher rates during periods of high demand and lower rates during periods of low demand. Energy providers could then capitalise on this pricing structure by storing energy during low-demand periods and releasing it at a premium during high-demand intervals. This offers lucrative potential for energy providers to invest in battery technology. However, the adoption of such solutions would require Singapore to further liberalise its energy market, allowing for energy trading and arbitrage—a model successfully demonstrated in the United States.

8. Recommendations

Scenario	Solution	Time Horizon
Deployment of renewable energy is slower than expected, leading to no demand for ESS	**Financial incentives** for privately owned buildings to install solar PVs and **R&D to explore offshore floating solar** in remote sea areas	**Short term**
Deployment of renewable energy is on track, leading to demand for ESS	Installation of **rooftop battery** and **recycling of EV batteries**	**Short to medium term**
Deployment of renewable energy is faster than expected, leading to high demand for ESS	Development of **an efficient market** through **encouraging smart metering adoption and establishing VPP**	**Long term**

Table 8.1: Possible Scenarios for Singapore's Renewable Energy Landscape

8.1 Provide Financial Incentives for Privately Owned Buildings to Install Solar PVs

Singapore saw wide scale adoption of solar PV on public buildings and public housing since 2014 as a result of the SolarNova program. The SolarNova program was launched in 2014. The programme is a Whole-Of-Government effort led by the EDB and HDB to accelerate the deployment of PV systems on government owned buildings in Singapore (Housing Development Board, 2023). This programme aggregates demand for solar PV across government agencies to achieve economies of scale, driving the growth of Singapore's solar industry. Additionally, HDB offers solar developers a percentage of the initial start-up funding as an incentive, and eventually, the town council purchases the solar system at the end of the lease (Chen, 2022).

However, incentives for solar PV implementation in commercial buildings have been neglected, leading to lower penetration rates. A study by SolarAI in 2020, found that buildings owned by private companies have by far the most untapped rooftop solar potential of 1,379 MW (Chew, 2020). This represents 50% more than the current total installed solar capacity of Singapore as of 2022.

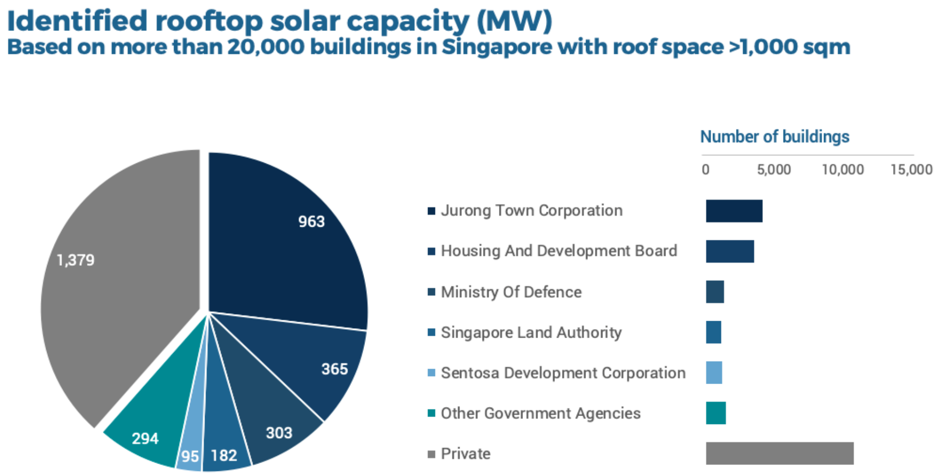

Figure 8.1: Identified Rooftop Solar Capacity (MW) in Singapore (Solar AI Technologies, 2022)

Besides rooftop PVs, building integrated photovoltaics (BIPV) can also be a potential solution to maximise this potential. BIPV are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, windows, or facades (Strong, 2016).

However, currently, 30% of private building owners in Singapore view these installations unfavourable (Oh, 2023). The main reasons cited were high upfront costs for installations, high maintenance costs, a lack of government incentives to support the adoption of such technology, and a lack of clear revenue and business models for BIPV. Moreover, building owners estimated that BIPVs would only add 1-3% of value to their buildings, not sufficient enough for them to add solar PVs to their buildings.

In Singapore’s context, from the primary and secondary research in this report, it is evident that cost is a key issue in private companies’ decision to adopt renewable energy. Upfront costs and payback period are two key metrics which these companies look at to aid their decisions. Unfortunately, Singapore’s current financial incentives are mainly focused on R&D rather than project subsidies and implementation incentives. As mentioned in section “Key Insights from Secondary Research”, we recommend Singapore to reference Thai’s ENCON fund which provides fundings for a wide range of solutions in energy conservation programs in both public and private sectors, with specific programmatic instruments to target particular beneficiaries. By adapting to Singapore’s context, incentives to reduce the upfront cost for these companies could boost solar PV adoption in privately owned buildings. Similarly, the source of this non-budgetary fund in Singapore could originate from levies on petroleum or carbon taxes - which are already used to support decarbonisation efforts, the transition to a green economy (National Environment Agency, 2023).

8.2 Construction of Offshore Floating Solar Panel to Spur Energy Generations

Due to its limited land area, Singapore's ability to harness solar energy has been constrained. Even though there is room for growth in the adoption of rooftop solar panels, solar PV installations on rooftops must be carefully considered in light of other important urban features, such as green spaces, water storage facilities, and crucial infrastructure (Gorman & Bandera, 2022). These elements limit the area that can be used for rooftop PV construction. To address this challenge, floating solar panels present a viable alternative, boasting up to a 13% increase in efficiency compared to land-based systems given the cooling effect of water. The 5 MW-peak system situated on the Strait of Johor is a notable illustration of floating solar innovation in Singapore. With a potential yearly output of almost 6 million kilowatt-hours, this facility is one of the biggest floating solar farms in the world.

Despite the existence of near-shore and in-land floating solar systems, Singapore has not yet created an offshore sea-based solar farm. Remote sea areas typically lack competing interests like shipping or recreation compared to near-shore space and offer limitless potential for solar energy generation (Hooper et al., 2021). By conducting additional research and development in this area, Singapore will be able to better utilise its marine area, increasing its total potential to generate solar energy.

8.3 Installation of Recycled EV Batteries on Rooftop Solar

The primary challenge in Singapore's solar energy deployment has long been land constraints. To maximise available space for the expansion of solar energy infrastructure, rooftop solar installations have emerged as a viable and immediate solution (Gorman, 2022). According to the 2020 SERIS report, the total usable rooftop area for PV deployment amounts to approximately 13.2 square kilometres. Through collaborative efforts among various stakeholders, 8,400 HDB blocks have already joined the SolarNova program, committing to the installation of rooftop solar energy systems (EMA, 2023)

Figure 8.2: Rooftop Solar Panels

To address the challenges posed by solar intermittency, Singapore has taken proactive steps by investing in ESS. One notable example is the deployment of a 285 MWh Sembcorp ESS on Jurong Island, which has the capacity to meet the electricity needs of approximately 24,000 four-room HDB households for a full day. However, as Singapore's solar energy capacity continues to expand, the cost-effectiveness of building more batteries on Jurong Island comes into question, as transmitting energy from there to HDBs could result in significant power losses. Case studies from India have shown that co-locating battery storage with solar generation sites can offer a more cost-effective solution.

Therefore, in the short to medium term, it may be practical to consider installing batteries at rooftop solar sites to optimise the efficiency of ESS. Australia serves as a primary case study in this regard, with around 180,000 households already equipped with battery systems (Mercer, 2023). Given Singapore's current lower solar energy capacity, installing a battery at each residential block should suffice to address intermittency issues. Furthermore, the utilisation of AI solutions, such as those offered by Solar AI Technologies, which are capable of assessing the solar potential of rooftops, can aid in better estimating the required storage capacity before implementation.

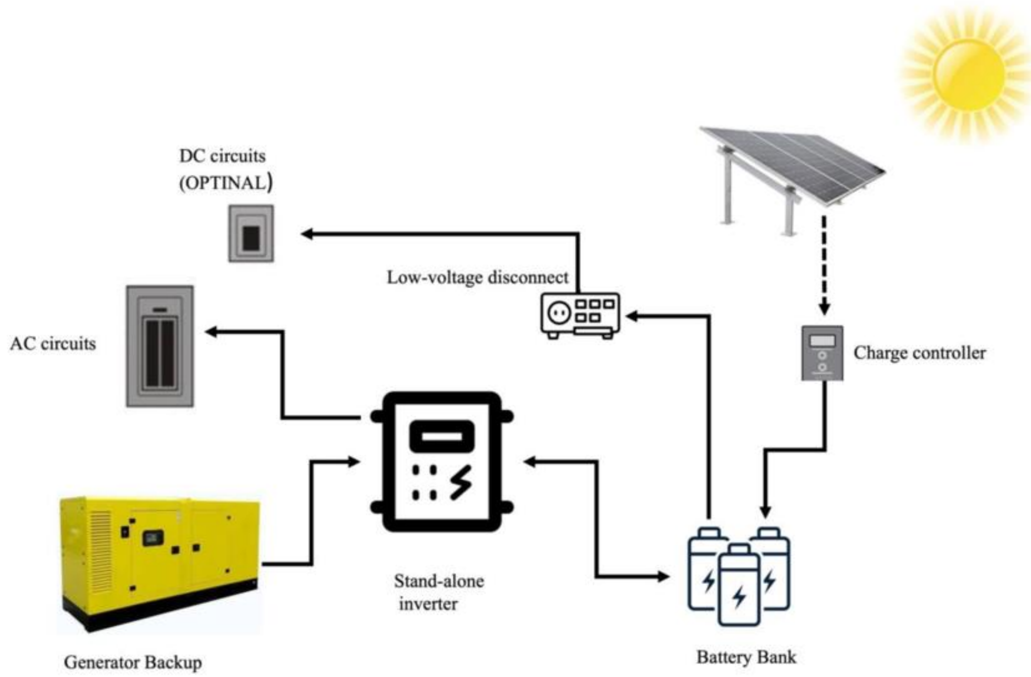

Figure 8.3: Rooftop Solar ESS Mechanism

While this solution has proven to be technically viable, achieving commercial viability remains a significant challenge. In addition to the government subsidies mentioned earlier, the recycling of EV batteries emerges as a key initiative to reduce costs. Malaysia provides notable case studies where the repurposing of used EV batteries has been heavily implemented. These activities help in building a circular ESS ecosystem that not only optimises used batteries for second-life applications but also recycles End-of-Life (EOL) ESS units to recover valuable resources for the economy. In Singapore, the feasibility of this solution is further supported by the fact that the EMA has already initiated a pilot program in collaboration with GenPlus to efficiently repurpose EV batteries for ESS applications (EMA, 2022). To repurpose used EV batteries for second-life purposes (such as grid-related applications) in Singapore, facilities and expertise would need to be developed to evaluate the current condition of these batteries and refurbish them to be fitted into new modules.

8.4 VPP System

A VPP is a network of decentralised, medium-scale power generating units as well as flexible power consumers and storage systems. In general, the goal is to connect distributed energy resources so that they may be tracked, forecasted, optimised, and traded for power (next kraftwerke, 2023). The deployment of distributed energy resources (DERs), such as solar panels, BESS and EVs has increased in response to environmental concerns about energy generation and the cost-competitiveness of renewable energy sources (Clean Energy Council, 2023). These DERs are intended to supplement conventional power plants that produce electricity centrally.

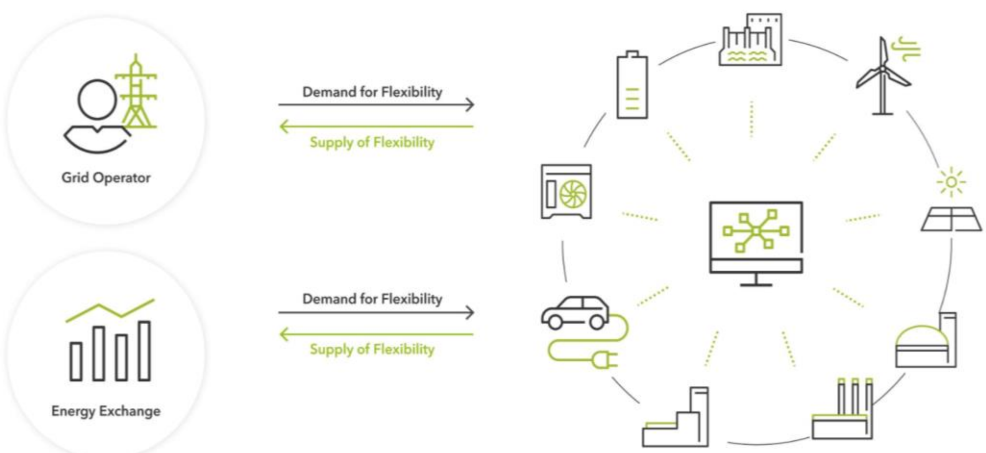

Figure 8.4: VPP Illustration (next kraftwerke, 2023)

Singapore is still at the preliminary stage of VPP development. The EMA and Sembcorp Industries (Sembcorp) have jointly awarded a grant to Nanyang Technological University to develop Singapore's first VPP in 2019 (Chan, 2019). Stakeholders' participation is important to build a VPP system. Singapore case is as below:

VPP Stakeholders	Singapore Case
Energy Producers and Generators: These could be conventional power plants or sources of renewable energy like solar, wind, hydro, etc. They provide the energy supply that powers the VPP	**Singapore has centralised renewable generators.** To promote VPP, we need to have distributed energy resources such as solar panels, BESS and EVs to act as renewable generators
VPP Operators: The organizations accountable for overseeing and running the VPP. Within the VPP, they combine, optimise, and synchronize the distributed energy resources (DERs) to guarantee grid efficiency and stability	There are no VPP operators in Singapore currently
Grid Operators and Utilities: These entities hold the accountability for maintaining the grid's operation. To make sure the VPP's contributions comply with both grid requirements and laws, they keep tight collaboration with VPP operators	**SP Group:** owns and operates Singapore's electricity network. **EMC (Energy Market Company)** serves as the Market Operator for Singapore's wholesale electricity market, which is known as the National Electricity Market of Singapore (NEMS)
Regulatory Bodies and Government Agencies: These organizations supervise and control VPP activities, making sure that energy market policies, safety requirements, and environmental laws are followed	**Energy Market Authority:** In order to promote more innovative concepts like VPP and to turn residential consumers into prosumers, there are ongoing

	discussions between EMA and EMC to develop regulatory standards and improve market mechanisms
Energy Storage Providers: Producers and managers of ESS that are connected into the VPP. They also offer software and hardware support for technical issues	Singapore needs to have a market leader of battery providers such as Tesla and LG Chem

Table 8.2 Key VPP Stakeholders in Singapore

In order to enhance the development of VPP, Singapore can learn from other countries by first increasing the deployment of distributed energy resources. The country is indeed making significant progress as the EMA and Singapore Institute of Technology (SIT) are partnering to develop and test-bed Singapore's largest Vehicle-to-Grid (V2G) technology to provide grid services (SIT, 2023). Furthermore, new regulations need to be introduced to promote VPP business models by creating demand via policies (e.g., ESS is required for secondary supply in buildings) and allowing residential ESS owners to become prosumers (Energy Market Authority, 2019) (SOMASUNDARAM, CHIAM, & Ming Chou, 2020).

Although there is a substantial market possibility, the current problems primarily relate to the commercial obstacles. Businesses that can overcome these obstacles will find a big reward on the other side. Based on the case study of Australia, the best way to start selling VPPs is to utilise the available data and sell batteries into the most lucrative market opportunities. Besides developing regulatory standards for ESS and VPP, Singapore needs solar power developers to break into the market, build customer base and lead the development.

8.5 Expansion and Improvement of Smart Metering System

In the future, when Singapore ramps up production capacity for renewable energy and renewable energy gets highly incorporated into the power grid, we propose a more efficient energy management system with smart metering. Singapore has implemented beyond 500,000 smart electricity across the country and is set to complete all 1.4 million meters for households by 2024 (SP Group, 2023). However, Singapore is still in a nascent stage of smart metering development. When more renewable energy is available in the market, a more efficient energy management system would be required to improve energy efficiency and reduce emission.

With reference to Australia's smart metering system, we propose the following changes to current smart metering system:

1) Expansion of current scale of smart metering to cover buildings across the nation. This would help with carbon emission objectives as more consumers can make informed choices about the usage of electricity and be incentivised to cut their usage.
2) Establishment of prosumer scheme whereby consumers have the option to sell stored energy into the wholesale market when prices go up. The potential to gain financial return from participating in energy trading would incentivise them to save energy and ease pressure on the power grid. Price restrictions may be set for individual retailers in the market based on market dynamics and associated trading regulations.
3) Synergy with VPP proposed above, whereby VPP aggregates the power of several rooftop solar units and pools together to serve the power grid. Individual smart metres can integrate with the VPP in the electricity system to reflect the real-time demand, supply and prices in the general wholesale market. Consumers can then make their decisions for energy usage or trading accordingly. This would make the demand response program more robust.

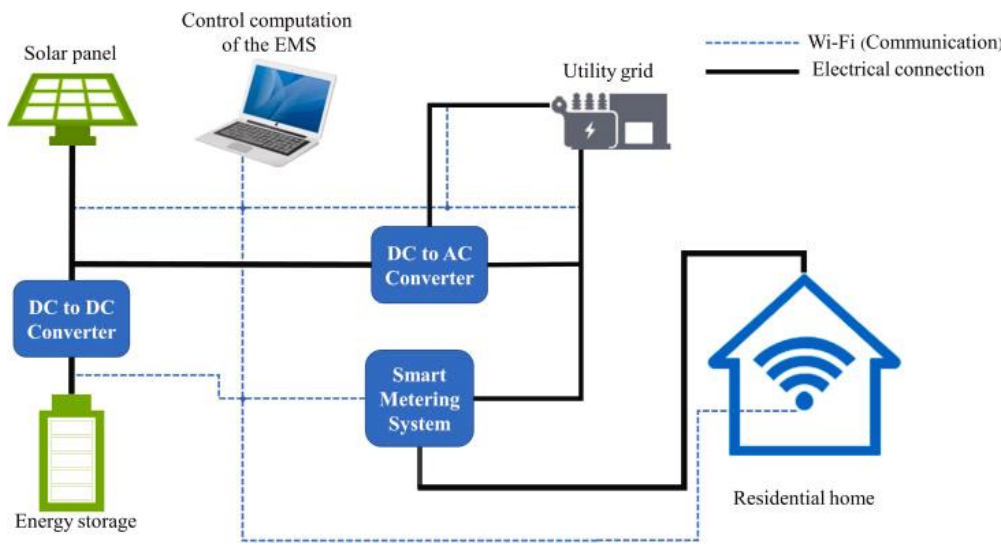

Figure 8.6: Illustration of Smart Metering System (Mbungu et al., 2020)

9. Discussion and Conclusion

This study aims to examine Singapore's current status in the realm of renewable energy, specifically solar energy and ESS, examine key challenges faced by Singapore and propose a thorough strategic roadmap to steer our nation towards a sustainable future.

Through comprehensive literature review, we have identified the following key bottlenecks to Singapore renewable energy development: the constraint of limited available land, the absence of financial incentives linked to solar panel deployment and ESS, and a lack of efforts to scale up ESS to address the escalating intermittency issues accompanying the growth of solar capacity.

To address those issues and introduce potential recommendations, we have conducted a holistic landscape study of renewable energy and ESS solution of other countries in APAC and expert views from industry professionals, our recommendations include enhanced government incentives, R&D in floating solar technologies, installation of recycled EV batteries on rooftop solar, integrated into VPP system, and a more efficient energy market in the long run. This set of recommendations addresses both cases of low and high demand for ESS dependent on the progress of solar energy roll out.

Nevertheless, it's important to acknowledge that our research has leaned heavily on literature reviews and expert interviews, and as such, it may lack a deep technical perspective. While our recommendations have been primarily drawn from best practices in other countries that have proven to be both technically and commercially viable, their applicability within Singapore's unique context deserves further investigation. Future research should, therefore, aim to delve deeper into the technical implementation aspects of these recommendations. This may require on-the-ground fieldwork and a more thorough understanding of the specific requirements necessary to make these recommendations feasible in Singapore's local context.

Furthermore, future research endeavours could also broaden the profile of primary research interviewees. Presently, the focus has been mainly on experts and industry professionals. However, considering that renewable energy initiatives and ESS solutions in Singapore have often been driven from the top-down, involving government stakeholders in our research could provide valuable insights, particularly from a financial feasibility perspective. This broader engagement with relevant stakeholders, including those from the EMA, would contribute to a more comprehensive understanding of the challenges and opportunities within Singapore's renewable energy landscape.

10. Acknowledgement

The authors would like to express our sincere gratitude to Professor Lawrence Loh and Verity Thoi of the National University of Singapore Centre for Governance and Sustainability (NUS CGS) for their invaluable assistance and guidance throughout the research process. Their insightful suggestions greatly contributed to the development of this research piece.

We would also like to thank the industrial experts who have provided us with invaluable insights during our primary research. Their titles and companies are listed below:

- Engineering Manager at Gurīn Energy
- Project Development, Enedis
- Business Development at Total Energy
- Principal Investments Analyst at Macquarie Capital

Additionally, we extend our appreciation to the National University of Singapore (NUS) for their support, which enabled us to undertake this meaningful project.

11. Reference

Aboitiz Renewables Inc. . (2023, August 9). *Opinion: Revolution: Overcoming challenges, seizing opportunities for renewables in ph*. AboitizPower Official Website. https://aboitizpower.com/news/renewable-energy/opinion-revolution-overcoming-challenges-seizing-opportunities-for-renewables-in-ph

AEMO. (2022). *2022 system strength report - australian energy market operator.* https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/operability/2022/2022-system-strength-report.pdf?la=en

AGEP. (2019, January 30). *Malaysia Energy Sector - ASEAN-German Energy Programme*. ASEAN. https://agep.aseanenergy.org/country-profiles/malaysia/malaysia-energy-sector/#1524896697001-ab31a2e1-3ebc6816-e5dc

Apanada, M. J., & Kaldjian, E. (2021, July 29). *Why the time is right for renewable energy in the Philippines*. World Resources Institute. https://www.wri.org/insights/renewable-energy-opportunity-philippines

Australia Trade and Investment Commission. (2023). *Solar Energy: Australia's Renewable Energy Leader*. Global Australia. https://www.globalaustralia.gov.au/industries/net-zero/solar-energy

Australia PV Institute. (2023, June). *Market Analyses*. https://pv-map.apvi.org.au/analyses#:~:text=As%20of%2030%20June%202023,capacity%20of%20over%2032.1%20gigawatts.

ASEAN Centre for Energy. (2020). *Singapore: How to Attract More Investment in Renewable Energy?* Policy Breif. https://aseanenergy.sharepoint.com/PRA/ACCEPT/Forms/AllItems.aspx?id=%2FPRA%2FACCEPT%2FACCEPT%20Web%20Content%2FPublication%2FPolicy%20Brief%2FRE%20Investment%20Series%5Fwith%20Number%2FPolicy%20Brief%20No%2E11%20RE%20Investment%20Series%20%2D%20Singapore%2Epdf&parent=%2FPRA%2FACCEPT%2FACCEPT%20Web%20Content%2FPublication%2FPolicy%20Brief%2FRE%20Investment%20Series%5Fwith%20Number&p=true&ga=1

Asian Development Bank. (2016). *Sector Overview: Thailand's Energy Market*. Report. https://www.adb.org/sites/default/files/linked-documents/49087-001-so.pdf

Asian Development Bank. (2019, December). *Southern Thailand Wind Power and Battery Energy Storage Project: Report and Recommendation of the President.* https://www.adb.org/projects/documents/tha-53174-001-rrp

Asian Development Bank. (2020, May 18). *ADB Finances First Wind Power and Battery Storage Project in Thailand.* Asian Development Bank. https://www.adb.org/news/adb-finances-first-wind-power-and-battery-storage-project-thailand

Asian Development Bank. (2020, September). *Renewable Energy Tariffs and Incentives in Indonesia: Review and Recommendations*. Asian Development Bank. Retrieved November

19, 2023, from https://www.adb.org/publications/renewable-energy-tariffs-incentives-indonesia

Asian Development Bank. (2020, September 15). Renewable energy tariffs and incentives in Indonesia: Review and recommendations. https://www.adb.org/publications/renewable-energy-tariffs-incentives-indonesia

Australian Government. (2023, November). *National Reconstruction Fund news*. Department of Industry, Science and Resources. Retrieved November 19, 2023, from https://www.industry.gov.au/news/national-reconstruction-fund

Bagaskara, A., Hapsar, A., Kurniawan, D., Tumiwa, F., Vianda, F., Padhilah, F. A., Wismadi, F. S., & Puspitarini, H. D. (2022). Indonesia Energy Transition Outlook 2022 - IESR. Indonesia Energy Transition Outlook 2023. https://iesr.or.id/wp-content/uploads/2021/12/IETO_2022_Outlook.pdf

Banzuelo, N. (2021). *San Miguel allots at least $1B for battery storage projects.* Busimess World. https://www.bworldonline.com/corporate/2021/04/22/362646/san-miguel-allots-at-least-1b-for-battery-storage-projects/

Bernama. (2023, February 22). *Malaysia's approach towards Renewable Energy*. BERNAMA. https://www.bernama.com/en/thoughts/news.php?id=2166297

Bhambhani, A. (2022, June 1). *Japan offering subsidies for small scale solar. Solar On Farmland, Ponds & Waste Disposal Sites Eligible For Rebate In Japan.* https://taiyangnews.info/tenders/japan-offering-subsidies-for-small-scale-solar/

Bian, L. (2023, June*). China's role in scaling up energy storage investments*.. https://doi.org/10.1016/j.enss.2023.03.002

BlackRidge. (2023, May 26). *South Korea Energy Storage Systems Market Outlook to 2028*. Blackridge Research & Consulting. Retrieved November 19, 2023, from https://www.blackridgeresearch.com/reports/southkorea-ess-market

Blackridge Research. (2023, July). *Pavagada Solar Park: India's second largest photovoltaic Solar Project*. Pavagada Solar Park: India's Second Largest Photovoltaic Solar Project. https://www.blackridgeresearch.com/project-profiles/pavagada-second-largest-solar-photovoltaic-plant-farm-park-in-india#:~:text=The%20massive%20Pavagada%20Solar%20Park,power%20plants%20in%20the%20world.

Bloomberg. (2020, May 11). *Battery making in Indonesia can cost less than in China*. BloombergNEF. https://about.bnef.com/blog/battery-making-in-indonesia-can-cost-less-than-in-china/

Bloomberg. (2023, July 13). *China takes Solar Farms to sea in next clean energy breakthrough*. Bloomberg. https://www.bloomberg.com/news/features/2023-07-13/china-takes-solar-farms-to-sea-in-next-clean-energy-breakthrough

Brockett, M. (2023, August 8). *New Zealand ties up with Blackrock in drive for fully green power.* The Japan Times. https://www.japantimes.co.jp/news/2023/08/08/asia-pacific/new-zealand-green-energy/

Bu, Y., & Zhang, X. (2020, March 26). *The Prospect of New Provincial Renewable Portfolio Standard in China Based on Structural Data Analysis*. Frontiers. https://www.frontiersin.org/articles/10.3389/fenrg.2020.00059/full

Calonzo, A., & Malik, N. S. (2023, May 22). *China's Solar Boom Is Already Accelerating Past Last Year's Record Surge*. Bloomberg.com. Retrieved November 19, 2023, from https://www.bloomberg.com/news/articles/2023-05-22/china-s-solar-power-boom-is-accelerating-past-last-year-s-record-surge

Chandak, P. (2023, July 25). *Indonesia achieves 322.6 MW solar power plant capacity in first half of 2023*. SolarQuarter. https://solarquarter.com/2023/07/25/indonesia-achieves-322-6-mw-solar-power-plant-capacity-in-first-half-of-2023/#:~:text=Indonesia%20Achieves%20322.6%20MW%20Solar%20Power%20Plant%20Capacity%20In%20First%20Half%20Of%202023,-By&text=The%20Indonesian%20Ministry%20of%20Energy,source%20for%20the%20nation's%20future

Chan, S. J. (2019, October 8). *Sembcorp, EMA jointly award grant to NTU to develop Singapore's first virtual power plant*. Yahoo Finance. https://sg.finance.yahoo.com/news/sembcorp-ema-jointly-award-grant-031542293.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAMGcTiSoR9bCExFe63zhQMc_1tPZDvuL5arguQEzqscdYVlggpPt4CU5jXtUQORmI3ckZqzDW0wo9Tx6S0UBTS5hytd05dLmetqst-fVnlanSCKR4NSQdJXwMkEaalWJK0TkYtJ6Oy-7iu33mcGqHfyBYXUbmRJp1mPKdazsqtfn

Chen, T., An, Y., Heng, C.K. (2022, August 2022). *A Review of Building-Integrated Photovoltaics in Singapore: Status, Barriers, and Prospects.* https://www.mdpi.com/2071-1050/14/16/10160

Clean Energy Council. (2023, April). *Clean energy report*. https://www.cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-repor

Clean Energy Council. (2023*). Home Page.* https://www.cleanenergycouncil.org.au/resources/technologies/energy-storage

Chew, B. (2020, October 4). *3.6 Gigawatts of Untapped Commercial Solar Potential in Singapore.* SolarAI. https://getsolar.ai/blog/untapped-solar-potential-singapore/

China Briefing. (2023). *China's Energy Storage Sector: Policies and Investment Opportunities - China Guide | Doing Business in China*. China Briefing. Retrieved November 19, 2023, from https://www.china-briefing.com/doing-business-guide/china/sector-insights/china-s-energy-storage-sector-policies-and-investment-opportunities

China Dialogue. (2022, August 18). *China to set up special purpose firms to tackle unpaid renewables subsidies*. China Dialogue. https://chinadialogue.net/en/digest/china-special-purpose-firms-to-tackle-unpaid-renewables-subsidies/

China Energy Storage Alliance. (2023, September 19). *Summary of Global Energy Storage Market Tracking Report (Q2 2023 Report) — China Energy Storage Alliance*. China Energy Storage Alliance. http://en.cnesa.org/latest-news/2023/9/19/summary-of-global-energy-storage-market-tracking-report-q2-2023-report

Chipman Koty, A. (2023, January 11). *Philippines opens renewable energy to full foreign ownership.* ASEAN Business News. https://www.aseanbriefing.com/news/philippines-opens-renewable-energy-to-full-foreign-ownership/

Chong, S. (2023, April 11). *Miti launches Malaysia's first Battery Energy Storage System for Renewable Energy*. BusinessToday. https://www.businesstoday.com.my/2023/04/11/miti-launches-malaysias-first-battery-energy-storage-system-for-renewable-energy/

Clifford Chance. (2021). *The renewable energy transition and solving the storage problem.* https://www.cliffordchance.com/content/dam/cliffordchance/briefings/2021/03/The-renewable-energy-transition-and-solving-the-storage-problem-a-look-at-japan.pdf

Climate Action Tracker. (2022, November 3). *China Climate Action Tracker*. https://climateactiontracker.org/countries/china/

Climate Action Tracker. (2023, July 17). *South Korea*. Climate Action Tracker. Retrieved November 19, 2023, from https://climateactiontracker.org/countries/south-korea/

Climate Policy Database. (2022, April 8). *The Fifth Basic Plan for Use, Supply and Technology Development of New and Renewable Energy (Fifth New and Renewable Energy Basic Plan) 2020-2034*. Climate Policy Database. Retrieved November 19, 2023, from https://www.climatepolicydatabase.org/policies/fifth-basic-plan-use-supply-and-technology-development-new-and-renewable-energy-fifth-new

Colthorpe, A. (2022a, November 7). *New Zealand's first 100MW grid-scale battery storage project gets approval*. Energy Storage News. https://www.energy-storage.news/new-zealands-first-100mw-grid-scale-battery-storage-project-gets-approval/

Colthorpe, A. (2023a, May 11). *Vietnam's first grid-connected battery storage system to be integrated by Honeywell*. Energy. https://www.energy-storage.news/vietnams-first-grid-connected-battery-storage-system-to-be-integrated-by-honeywell/

Colthorpe, A. (2023, July 3). *"make in Vietnam" partnership for rooftop solar and Integrated Battery Storage Solutions*. Energy. https://www.energy-storage.news/make-in-vietnam-partnership-for-rooftop-solar-and-integrated-battery-storage-solutions/#:~:text=Vietnam%27s%20VinES%20Energy%20Solutions%20has,in%20the%20Southeast%20Asian%20country.

Colthorpe, A. (2023, June 27). *First Bess in Japan to commercially trade energy commissioned by country's biggest solar developer.* Energy. https://www.energy-storage.news/first-bess-in-japan-to-commercially-trade-energy-commissioned-by-countrys-biggest-solar-developer/

Colthorpe, A. (2022b, November 29). *Philippines regulators consider energy storage ownership rules and definition – report.* Energy Storage News. https://www.energy-storage.news/philippines-regulators-consider-energy-storage-ownership-rules-and-definition-report/

Colthorpe, A. (2023, August 23). *South Korea offers central market contracts for 260MWh energy storage in Jeju Island tender*. Energy-Storage.News. Retrieved November 19, 2023, from https://www.energy-storage.news/south-korea-offers-central-market-contracts-for-260mwh-energy-storage-in-jeju-island-tender/

Das, K. (2019, December 5). *Vietnam's solar power market*. Vietnam Briefing News. https://www.vietnam-briefing.com/news/vietnams-solar-power-market.html/

Department Of Energy. (2023). *Department of Energy Philippines*. https://www.doe.gov.ph/rule-5-generation-sector

Ditrolic Energy. (2023). *Battery Energy Storage System Malaysia: Maximising Clean Energy Performance.* https://www.ditrolicenergy.com/en-us/media/publications/innovation/november-2022/battery-energy-storage-system

Ditrolic Energy. (2022, November 23*). Battery Energy Storage System Malaysia: Maximising Clean Energy Performance*. https://www.ditrolicenergy.com/en-us/media/publications/innovation/november-2022/battery-energy-storage-system

Dong, X. (2023, May 31). *China Electricity Mix April update 2023*. Climate Energy Finance. Retrieved November 19, 2023, from https://climateenergyfinance.org/wp-content/uploads/2023/05/China-Electricity-Mix-April-update-2023.pdf

EBUCHI, T. (2022, January 26*). Japan to open up power grids to battery storage for renewables.* Nikkei Asia. https://asia.nikkei.com/Business/Energy/Japan-to-open-up-power-grids-to-battery-storage-for-renewables

Economic Development Board, Singapore. (2022, October 12). *ASEAN set to play key role in global solar supply chain.* https://www.edb.gov.sg/en/business-insights/insights/asean-set-to-play-key-role-in-global-solar-supply-chain.html#:~:text=Thailand%2C%20the%20largest%20producer%20of,20%20per%20cent%20in%202021

Economics Information Daily (经济参考报）. (2022, June 6). *弃风弃光局地抬头新能源堵点待通_经济参考网*. 经济参考报. Retrieved November 19, 2023, from http://dz.jjckb.cn/www/pages/webpage2009/html/2022-06/06/content_84541.htm

Editor. (2023, May 10*). Re policy: Placing Malaysia at the centre of Regional Electricity Trade.* BusinessToday. https://www.businesstoday.com.my/2023/05/10/re-policy-placing-malaysia-at-the-centre-of-regional-electricity-trade/

Ehsanul Kabir, E., Kumar, P., Kim, K.-H., Adelodun, A. A., & Kumar, S. (2017). *Solar energy potential and future prospects in Afar Region, Ethiopia. American Journal of Modern Energy.* https://doi.org/10.11648/j.ajme.20210702.12

Ember. (2023, May 23). *Malaysia: Electricity transition*. https://ember-climate.org/countries-and-regions/countries/malaysia/

Energy, G. (2023, February 2). *Malaysia renewables growth hindered by absence of robust policies*. Power Technology. https://www.power-technology.com/comment/malaysia-renewables-growth/

Energy Market Authority. (2018, October 30). *Energy Storage Systems for Singapore*. EMA Singapore Policy Paper. https://www.ema.gov.sg/content/dam/corporate/regulations/policy-papers/pdf-files/EMA-Regulations-Policies-Policy-on-Energy-Storage-Systems-for-Singapore.pdf

Energy Market Authority. (2023). *Our Energy Story.* EMA Singapore. https://www.ema.gov.sg/our-energy-story

Energy Market Authority. (2023). *Speech by Mr S Iswaran.* EMA Singapore. https://www.ema.gov.sg/news-events/news/speeches/speech-by-mr-s-iswaran-second-minister-for-trade-industry-during-the-committee-of-supply-debate-ministry-of-trade-industry

Energy Market Authority. (2023, August 3). *Sunny Days Ahead for Solar Adoption in Singapore*. EMA Singapore. https://www.ema.gov.sg/news-events/news/feature-stories/sunny-days-ahead-for-solar-adoption-in-singapore#:~:text=This%20has%20made%20Singapore%20to,gigawatt%2Dpeak%20(GWp)

Energy Market Authority. (2023). *Energy Storage Systems*. EMA Singapore. https://www.ema.gov.sg/our-energy-story/energy-grid/energy-storage-systems

Energy Market Authority. (2023, August 2). *Home*. https://www.ema.gov.sg/news-events/news/feature-stories/sunny-days-ahead-for-solar-adoption-in-singapore

Energy Market Authority. (2019, October 8). *Singapore's First Virtual Power Plant to Optimise Energy Distribution*. https://www.ema.gov.sg/news-events/news/media-releases/singapores-first-virtual-power-plant-to-optimise-energy-distribution

energystorageforum. (2020). *BUILDING A VPP – SUCCESSFUL STRATEGIES FOR MARKET ENTRY.* https://energystorageforum.com/news/energy-storage/building-a-vpp-successful-strategies-for-market-entry

Frenoy, A. (2023). *Saft energy storage system to support New Zealand's transition to low-carbon electricity.* https://www.saft.com/media-resources/press-releases/saft-energy-storage-system-support-new-zealand%E2%80%99s-transition-low#:~:text=The%20complete%20BESS%20solution%20supplied,provided%20by%20third%2Dparty%20suppliers.

FUJIOKA, K. (2023, April 22). *Japan to subsidize half of costs for lithium and key mineral projects.* Nikkei Asia. https://asia.nikkei.com/Economy/Japan-to-subsidize-half-of-costs-for-lithium-and-key-mineral-projects

Gabrielle Kuiper. (2022). *What Is the State of Virtual Power Plants in Australia?* https://ieefa.org/wp-content/uploads/2022/03/What-Is-the-State-of-Virtual-Power-Plants-in-Australia_March-2022_2.pdf

Garcia, G. (2023, July 25). *Philippines has mixed reaction to China's $14bn for Clean Energy*. China Dialogue. https://chinadialogue.net/en/energy/chinese-investment-in-philippines-renewables/

GlobalData Energy. (2022, November 17*). Japan to nearly achieve 2030 renewable power generation target*. Power Technology. https://www.power-technology.com/comment/japan-2030-renewable-target/

Gorman, M., & Bandera, M. (2022, July). *Why is sunny Singapore not covered with rooftop solar panels?* https://www.channelnewsasia.com/commentary/singapore-renewable-energy-rooftop-buildings-solar-electricity-costs-2782796

Government of India. (2023, September 25). *Current status: Ministry of new and renewable energy, government of India*. Current Status | Ministry of New and Renewable Energy, Government of India. https://mnre.gov.in/solar/current-status/

Hasan, M., & Wahjosudibjo, A. S. (2014). Feed-In Tariff for Indonesia ' s Geothermal Energy Development , Current Status and Challenges. Semantic Scholar.

https://www.semanticscholar.org/paper/Efficient-Feed-In-Tariff-Policies-for-Renewable-Alizamir-V%C3%A9ricourt/8587ae1a647104d386366b631135e814314e93ac

Hawkins, A., & Cheung, R. (2023, June 28). *China on course to hit wind and solar power target five years ahead of time*. The Guardian. Retrieved November 19, 2023, from https://www.theguardian.com/world/2023/jun/29/china-wind-solar-power-global-renewable-energy-leader

Hayley, A. (2023, July 26). *China adds flexibility to power grids, builds storage capacity to avoid outages*. Reuters. Retrieved November 19, 2023, from https://www.reuters.com/business/energy/china-adds-flexibility-power-grids-builds-storage-capacity-avoid-outages-2023-07-26/

Hayley, A., & Wong, J. (2023, June 11). *China's installed non-fossil fuel electricity capacity exceeds 50% of total*. Reuters. Retrieved November 19, 2023, from https://www.reuters.com/business/energy/chinas-installed-non-fossil-fuel-electricity-capacity-exceeds-50-total-2023-06-12/

Hayley, A., & Wong, J. (2023, June 20). *China just met its 50% renewable energy target early*. SolarPACES. Retrieved November 19, 2023, from https://www.solarpaces.org/chinas-51-renewable-energy-target-was-achieved-early/

Hazarika. (2023, July). *Australia Global Leader in Battery Energy Storage Systems: Report - MERCOM India*. Mercomindia.com. https://www.mercomindia.com/australia-leader-battery-energy-storage-systems#

Hooper, T., Armstrong, A., & Vlaswinkel, B. (2021). *Environmental impacts and benefits of marine floating solar*. Solar Energy, 219, 11–14. https://doi.org/10.1016/j.solener.2020.10.010

Housing Development Board, HDB. (2023). *SolarNova Programme.* About Us. https://www.hdb.gov.sg/cs/infoweb/about-us/our-role/smart-and-sustainable-living/solarnova-page

Hu, X., Zou, C., Zhang, C., & Li, Y. (2017). *Technological Developments in Batteries: A Survey of Principal Roles, Types, and Management Needs*. https://ieeexplore.ieee.org/document/8011541

Hutchins, M. (2023, May 6). *Japan turns to the rooftop*. Weekend Read. https://www.pv-magazine.com/2023/05/06/weekend-read-japan-turns-to-the-rooftop/

Hydrogen Indonesia. (2022). Key takeaways about renewable energy in Indonesia. https://www.hydrogen-indonesia.id/green-hydrogen/in-indonesia/overview

International Energy Agency (IEA). (2020, November). *Korea 2020 – Analysis - IEA*. International Energy Agency. Retrieved November 19, 2023, from https://www.iea.org/reports/korea-2020

International Energy Agency (IEA). (2021, February). *India Energy Outlook 2021 – analysis*. IEA. https://www.iea.org/reports/india-energy-outlook-2021

International Energy Agency (IEA). (2021, July). *Renewables integration in India – analysis*. https://www.iea.org/reports/renewables-integration-in-india#

International Energy Agency (IEA). (2023). *Executive summary – Australia 2023 – analysis*. https://www.iea.org/reports/australia-2023/executive-summary

International Energy Agency (IEA). (2023). New Zealand 2023 Energy Policy Review. International Energy Agency. https://www.iea.org/events/new-zealand-2023-energy-policy-review

Ingram, E. (2023, April 10). India's Ministry of Power releases pumped storage hydro development guidelines. Retrieved November 18, 2023, from Hydro Review website: https://www.hydroreview.com/hydro-industry-news/pumped-storage-hydro/indias-ministry-of-power-releases-pumped-storage-hydro-development-guidelines/#gref

International Renewable Energy Agency (IRENA). (2017). *Renewable Energy Outlook Thailand.* Report. https://www.irena.org/-/media/files/irena/agency/publication/2017/nov/irena_outlook_thailand_2017.pdf

International Renewable Energy Agency (IRENA). (2022). *Renewable Power Generation Costs in 2022.* Report. https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022#:~:text=For%20newly%20commissioned%20onshore%20wind,2022%20to%20USD%200.049%2FkWh.

International Renewable Energy Agency IRENA. (2020) *Global Renewables Outlook: Energy Transformation 2050*. https://www.scirp.org/(S(lz5mqp453edsnp55rrgjct55.))/reference/referencespapers.aspx?referenceid=2835743

International Renewable Energy Agency IRENA. (2021, January 1). *Renewable energy auctions in Japan: Context, design and results*. https://www.irena.org/publications/2021/Jan/Renewable-energy-auctions-in-Japan

ITA (2022, September 27). *Vietnam Solar Power Sector*. International Trade Administration | Trade.gov. https://www.trade.gov/market-intelligence/vietnam-solar-power-sector#:~:text=In%20the%20past%20two%20years,at%2017.6%20GW%20in%202021

ITA (2022, December 15). *Vietnam - power generation, transmission, and distribution*. International Trade Administration | Trade.gov. https://www.trade.gov/country-commercial-guides/vietnam-power-generation-transmission-and-distribution

Jain. (2023, May 16). *How India became a frontrunner in the global renewable energy market*. The Economic Times. https://economictimes.indiatimes.com/industry/renewables/how-india-became-a-frontrunner-in-the-global-renewable-energy-market/articleshow/100271905.cms?from=mdr#

Jantti, M., Jantti, A., & Shafie-Khah, M. (2022). Toward customer-centric power grid: Residential EV charging simulator for smart homes. *Decentralized Frameworks for Future Power Systems*, 207-226. https://doi.org/10.1016/B978-0-323-91698-1.00017-0

Jiang, Y., Geall, S., & Gao, B. (2022, June 23). *China's Five Year Plan for energy: One eye on security today, one on a low-carbon future*. China Dialogue. Retrieved November 19, 2023, from https://chinadialogue.net/en/climate/chinas-five-year-plan-for-energy-one-eye-on-security-today-one-on-a-low-carbon-future/

Jiang, Z., Dai, J., Saettone, S., Tørå, G., He, Z., Bashir, M., & Souto-Iglesias, A. (2023*). Design and model test of a soft-connected lattice-structured floating solar photovoltaic concept for harsh offshore conditions. Marine Structures, 90, 103426.* https://doi.org/10.1016/j.marstruc.2023.103426

Jones, D. (2023, February 14). *Global Electricity Review 2022*. Ember. https://ember-climate.org/insights/research/global-electricity-review-2022/

Kaur Kawan Singh, E. (2023, July 5). *Malaysia unleashes renewable energy potential on Singapore's doorstep.* New Straits Time. https://www.nst.com.my/opinion/columnists/2023/07/927722/malaysia-unleashes-renewable-energy-potential-singapores-doorstep

Kaur, I. (2021, September 17). Chapter 29 - Metering architecture of smart grid. *Advances in Nonlinear* Dynamics *and Chaos (ANDC)*, 687-704. https://doi.org/10.1016/B978-0-12-824555-2.00030-7

Kidmo, D. K., Bogno, B., Deli, K., & Goron, D. (2020). *Seasonal Wind Characteristics and Prospects of Wind Energy Conversion Systems for Water Production in the Far North Region of Cameroon.* https://www.scirp.org/journal/paperinformation.aspx?paperid=103292

KPMG. (2021). *R&D Tax Incentive & Government Grants: Renewable Energy*. KPMG. Retrieved November 19, 2023, from https://assets.kpmg.com/content/dam/kpmg/au/pdf/2020/r-d-tax-incentives-renewables-factsheet.pdf

Kwon, T.-H. (2020, June). Policy mix of renewable portfolio standards, feed-in tariffs, and auctions in South Korea: Are three better than one? *Utilities Policy*, *64*. https://doi.org/10.1016/j.jup.2020.101056

KYODO NEWS. (2022, December 15). *Tokyo to require new homes be fitted with solar panels from FY 2025*. Kyodo News+. https://english.kyodonews.net/news/2022/12/3c10f9876521-tokyo-to-require-new-homes-be-fitted-with-solar-panels-from-fy-2025.html

Lau, L.-S., Choong, Y.-O., Ching, S.-L., Wei, C.-Y., Senadjki, A., Choong, C.-K., & Seow, A.-N. (2022). *Expert insights on Malaysia's residential solar-energy policies: Shortcomings and recommendations.* Clean Energy, 6(4), 619–631. https://doi.org/10.1093/ce/zkac043

Lee, A. (2022, December 9*). Japan's first offshore Solar Farm to feed robot battery-mule boats with power for Tokyo. Japan's first offshore solar farm to feed robot battery-mule boats with power for Tokyo*. https://www.rechargenews.com/energy-transition/japans-first-offshore-solar-farm-to-feed-robot-battery-mule-boats-with-power-for-tokyo/2-1-1371227

Lee, J. Y., Ramasamy, A. K., Ong, K. H., Verayiah, R., Mokhlis, H., & Marsadek, M. (2023). *Energy Storage Systems: A review of its progress and outlook, potential benefits, barriers and solutions within the Malaysian Distribution Network*. Journal of Energy Storage, 72, 108360. https://doi.org/10.1016/j.est.2023.108360

Lee, S. (2022, July 6). *Korea's Renewable Energy Policy for Carbon NeutralityView Details | Industry Focus | InvestKOREA(ENG)*. Invest KOREA. Retrieved November 19, 2023, from https://www.investkorea.org/ik-en/bbs/i-308/detail.do?ntt_sn=490770

Lee, S., Amjad, M. M., Lee, E. K., & Cran-McGreehin, S. (2023, April 12). Clean energy policy. Ember. https://ember-climate.org/

Leussink, D. (2023, April 28). *Japan to give up to $1.8 billion in subsidies for storage battery, chip projects*. Reuters. https://www.reuters.com/markets/asia/japan-give-up-18-bln-subsidies-storage-battery-chip-projects-2023-04-28/

Lin, C. (2021, July 14). *Singapore unveils one of the world's biggest floating solar panel farms.* https://www.reuters.com/business/energy/singapore-unveils-one-worlds-biggest-floating-solar-panel-farms-2021-07-14/

Low, H. (2018, October 22). *Would Grid Battery storage work financially, in Singapore?* https://howardlhw.medium.com/would-grid-battery-storage-works-financially-in-singapore-771587a10844

Maguire, G. (2023, March 14). *Philippines set to go from renewable laggard to leader in SE Asia.* Reuters. https://www.reuters.com/markets/commodities/philippines-set-go-renewable-laggard-leader-se-asia-2023-03-14/

MBIE. (2023, August 17). *Energy in New Zealand 2023 shows renewable electricity generation increased to 87%.* Ministry of Business, Innovation and Employment. https://www.mbie.govt.nz/about/news/energy-in-new-zealand-2023-shows-renewable-electricity-generation-increased-to-87-percent/#:~:text=Energy%20in%20New%20Zealand%202023%20shows%20renewable%20electricity%20generation%20increased%20to%2087%25,-Published%3A%2017%20August&text=87%25%20of%20electricity%20generated%20over,into%20the%20energy%20sector%20shows.

Merk, P., Kuwahata, R., Rabe, S., Wakeyama, T., & Pescia, D. (2018*). Integrating renewables into the Japanese power grid by 2030.* https://www.renewable-ei.org/pdfdownload/activities/REI_Agora_Japan_grid_study_FullReport_EN_WEB.pdf

METI. (2022). *Battery storage to efficiently achieve renewable energy integration* ｜report: Renwable Energy Institute. Reports & Proposals | Renewable Energy Institute. https://www.renewable-ei.org/en/activities/reports/20230123.php

Ministry for the Environment. (2023, April 27). *About the New Zealand Emissions Trading Scheme*. https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/ets/about-nz-ets/

Murray, C. (2023, January 30). *Philippines Doe reveals draft Energy Storage Market Policy changes*. Energy Storage News. https://www.energy-storage.news/philippines-doe-reveals-draft-energy-storage-market-policy-changes/

MYBESS. (2023). Home Page. https://www.mybess.com.my/

McKinsey. (2022, October 14). *Charting a path for Vietnam to achieve its net-zero goals*. McKinsey & Company. https://www.mckinsey.com/capabilities/sustainability/our-insights/charting-a-path-for-vietnam-to-achieve-its-net-zero-goals

Mercer, D. (2023, March 29). *Australians seek "relief from the grid" as household battery uptake surges to record high*. ABC News. https://www.abc.net.au/news/2023-03-30/australian-household-battery-uptake-surges-to-record-high/102160138

Ministry of Finance, Singapore. (2023). *Governance and Policies.* https://www.mof.gov.sg/singapore-public-sector-outcomes-review/citizens/our-shared-future-and-place-in-the-world/government-and-regulations#:~:text=Overall%2C%20Singapore%20maintained%20the%20top,the%20World%20Bank%20in%202021.&text=A%20key%20pillar%20of%20being,remaining%20low%20over%20the%20years

Nadiq, S. (2022, December 6). *IEA: Countries to double renewable energy growth by 2027.* Power Technology. https://www.power-technology.com/news/iea-countries-to-double-renewable-energy-growth-by-2027/?cf-view

Natalie. (2023, August 28). Renewable energy regulations in the Philippines. Law.asia. https://law.asia/renewable-energy-regulations-philippines/

National Climate Change Secretariat. (2011). *Smart Grid Technology Primer.* NCCS Singapore. https://www.nccs.gov.sg/files/docs/default-source/default-document-library/smart-grid-technology-primer-a-summary.pdf

National Climate Change Secretariat. (2022). *Singapore Climate Action.* NCCS Singapore. https://www.nccs.gov.sg/singapores-climate-action/mitigation-efforts/power/

National Development and Reform Committee (NDRC). (2022, June 7). *【关于进一步推动新型储能参与电力市场和调度运用的通知】-国家发展和改革委员会*. 国家发展改革委. Retrieved November 19, 2023, from https://www.ndrc.gov.cn/xwdt/tzgg/202206/t20220607_1326855.html?code=&state=123

National Energy Administration (国家能源局）. (2021, December 21). *国家能源局关于印发《电力辅助服务管理办法》的通知国能发监管规〔2021〕61 号*. 国家能源局. Retrieved November 19, 2023, from http://zfxxgk.nea.gov.cn/2021-12/21/c_1310391161.htm

National Environmental Agency. (2023). *Carbon Tax.* Our Services. https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/climate-change/carbon-tax#:~:text=The%20carbon%20tax%20is%20applied,equivalent%20(tCO2e).&text=The%20carbon%20tax%20revenue%20collected,impact%20on%20businesses%20and%20households

National Grid. (2023). *What is liquified natural gas?* National Grid. https://www.nationalgrid.com/stories/energy-explained/what-is-liquefied-natural-gas-lng#:~:text=LNG%20produces%2040%25%20less%20carbon,harmful%20to%20the%20earth%27s%20atmosphere

National University of Singapore and Solar Energy Research Institute of Singapore (2020, March). *Update of the Solar PV Roadmap for Singapore.* Technical Report. https://www.seris.nus.edu.sg/doc/publications/Update-of-the-Solar-Roadmap-for-Singapore-(March-2020).pdf

Nanyang Technological University & Smart Grid and Power Electronics Consortium Singapore. (2019). *Grid 2.0.* https://www.ntu.edu.sg/docs/librariesprovider60/publications/grid-2-0.pdf?sfvrsn=c1803649_2

National Power Corporation. (2023, September). Home. Who we are. https://www.napocor.gov.ph/index.php/about-us/who-we-are

NDRC & NEA. (2022). *"十四五"新型储能发展实施方案*. 国家发展改革委. Retrieved November 19, 2023, from https://www.ndrc.gov.cn/xwdt/tzgg/202203/P020220321550104020921.pdf

Next Kraftwerke. (2023). *Virtual Power Plant How to Network Distributed Energy* https://www.next-kraftwerke.com/vpp/virtual-power-plant

New Zealand Government. (n.d.). *Wellbeing Budget 2023*. New Zealand Government. https://budget.govt.nz/budget/2023/wellbeing/approach/index.htm

NGCP. (2023). *Corporate profile - national grid corporation of the Philippines*. CORPORATE PROFILE. https://ngcp.ph/profile

Nguyen, D. (2021, March 2). *Electricity oversupply forces authorities to cut solar output - vnexpress international*. VnExpress International – Latest news, business, travel and analysis from Vietnam. https://e.vnexpress.net/news/business/industries/electricity-oversupply-forces-authorities-to-cut-solar-output-4239443.html

Nguyen, L. D. (2022, May 19). *Vietnam's renewable energy policies and opportunities for the private sector*. The National Bureau of Asian Research (NBR). https://www.nbr.org/publication/vietnams-renewable-energy-policies-and-opportunities-for-the-private-sector/

Noorfatima, N., Yang, Y., Jung, J., & Kim, J.-S. (2021, June 13). *Congestion Management by Allocating Network Use Cost for the Small-Scale DER Aggregator Market in South Korea*. MDPI. Retrieved November 19, 2023, from https://www.mdpi.com/1996-1073/14/12/3524

Ohbayashi, M. (2022). *Japan's transition toward a renewable energy future*. The National Bureau of Asian Research (NBR). https://www.nbr.org/publication/japans-transition-toward-a-renewable-energy-future/

Oh, S. (2023, August, 31). *More incentives needed to encourage wider use of solar panels among building owners: NUS poll.* Business Times. https://www.businesstimes.com.sg/property/more-incentives-needed-encourage-wider-use-solar-panels-among-building-owners-nus-poll

Ong, Y., & Calonzo, A. (2022, June 6). *China's Renewable Energy Fleet Is Growing Too Fast for Its Grid*. Bloomberg.com. Retrieved November 19, 2023, from https://www.bloomberg.com/news/articles/2022-06-06/china-s-renewable-energy-fleet-is-growing-too-fast-for-its-grid-l425v47z

Packham, C. (2022, November 6). *Regulator says smart meters for homes should be mandatory by 2030*. AFR. Retrieved November 19, 2023, from https://www.afr.com/companies/energy/smart-meters-should-be-mandatory-by-2030-20221104-p5bvrx

Park, W. Y., Khanna, N., Kim, J. H., Shiraishi, K., Abhyankar, N., Paliwal, U., Lin, J., & Phadke, A. (2023, April). *Korean Power System Challenges and Opportunities*. Publications | Energy Technologies Area Publications. Retrieved November 19, 2023, from https://eta-publications.lbl.gov/sites/default/files/korean_power_system_challenges_and_opportunities.pdf

pib.gov.in. (n.d.). *Mission on Advanced and High-Impact Research (MAHIR) launched to leverage Emerging Technologies in Power Sector* https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1930368

Port of Singapore Authority (PSA). (2022, July 14). *Singapore's first Energy Storage System at PSA's Pasir Panjang Terminal.* https://www.singaporepsa.com/2022/07/14/singapores-first-energy-storage-system-at-psas-pasir-panjang-terminal/

Power Technology. (2023, July 19). *Top five energy storage projects in Japan.* https://www.power-technology.com/data-insights/top-five-energy-storage-projects-in-japan/

Ministry of Trade and Industry. (2023). *Singapore's Energy Story.* https://www.poweringlives.gov.sg/about/singapore-energy-story/

Praiwan, Y. (2022, October 16). *New plan puts focus on clean power.* Bangkok Post. https://www.bangkokpost.com/business/2423496/new-plan-puts-focus-on-clean-power

Prime Minister’s Office. (2022, October 22). *DPM Lawrence Wong at the Singapore International Energy Week.* Prime Minister’s Office, Singapore https://www.pmo.gov.sg/Newsroom/DPM-Wong-at-Singapore-International-Energy-Week

Rai-Roche, S. (2021, July 7). *Japan almost doubles its solar target with 108GW planned by 2030.* https://www.pv-tech.org/japan-almost-doubles-its-solar-target-with-108gw-planned-by-2030/

Rakesh, R. (2023, March 6). *Foreign direct investment in India’s renewable sector dips 46% in Q3 FY 2023 - MERCOM India*. Mercomindia.com. https://www.mercomindia.com/foreign-direct-investment-indias-renewable-dips-fy-2023

Rana, P. (2020, July 15*). Japan’s energy sector and its supercharged benefits.* Tokyoesque. https://tokyoesque.com/japans-energy-sector/#Virtual_Power_Plants_VPP

RE100. (2023, March 14). *South Korean government must go further to support businesses wanting to use renewables*. RE100. Retrieved November 19, 2023, from https://www.there100.org/our-work/press/south-korean-localised-policy-messages

Reuters . (2020, February 3). *Philippines steps up security to shield power grid from foreign control.* Reuters. https://www.reuters.com/article/philippines-china-power-idUSL4N2A333F

Riva Sanseverino, E., Le Thi Thuy, H., Pham, M.-H., Di Silvestre, M. L., Nguyen Quang, N., & Favuzza, S. (2020, May 16). *Review of potential and actual penetration of solar power in Vietnam*. MDPI. https://www.mdpi.com/1996-1073/13/10/2529

Rapid Transition Alliance. (2023, January 25). *Viet Nam’s rapid rise to becoming a solar powered state*. https://rapidtransition.org/stories/viet-nams-rapid-rise-to-becoming-a-solar-powered-state/

San Miguel Corporation. (2023). *PBBM unveils SMC’s nationwide BESS network seen to power RP's clean energy transition*. https://www.sanmiguel.com.ph/news/pbbm-unveils-smcs-nationwide-bess-network-seen-to-power-rps-clean-energy-transition#:~:text=That%20pioneering%20BESS%20project%20introduced,the%20Philippines%20and%20Southeast%20Asia.

Shewali. (2017, December 6). *Kerala gets India’s largest floating solar plant, will produce 7.5 lakh units of power annually*. IndiaTimes. https://www.indiatimes.com/news/india/kerala-gets-india-s-largest-floating-solar-plant-it-will-produce-a-whopping-7-5-lakh-units-of-power-annually-331872.html

SHIGA, & SHIGENO. (2023, September 12). *Kawasaki, Aboitiz eye Philippine launch for renewable energy tech.* https://asia.nikkei.com/Business/Energy/Kawasaki-Aboitiz-eye-Philippine-launch-for-renewable-energy-tech

Shukla. (2022, December). *Top developments in the Indian Energy Storage Sector in 2021 - MERCOM India*. Mercomindia.com. https://www.mercomindia.com/top-developments-indian-storage-2021

Sirasoontorn, P., Koomsup, P. (2016). *Energy Transition in Thailand: Challenges and Opportunities.* https://library.fes.de/pdf-files/bueros/thailand/13888.pdf

Sinclair Digital. (2023, July). *Battery Energy Storage Systems (ESS)—Now is the Time for this Clear Winner.* Sinclair Digital. https://sinclair-digital.com/battery-energy-storage-systems-ess-now-is-the-time-for-this-clear-winner/

SIT. (2023, October 25). *Singapore's Largest Vehicle-to-Grid Test-bed to Assess Potential of Providing Grid Services. Retrieved November 18, 2023, from Singapore Institute of Technology* website: https://www.singaporetech.edu.sg/news/singapores-largest-vehicle-grid-test-bed-assess-potential-providing-grid-services#:~:text=The%20Energy%20Market%20Authority%20(EMA

Skrine. (2022). *Corporate Virtual Power Purchase Agreements in Malaysia: Skrine - Advocates & Solicitors.* Retrieved from https://www.skrine.com/insights/alerts/november-2022/corporate-virtual-power-purchase-agreements-in-mal

Solar Emporium. (2023, July 27). *Large-scale batteries supporting renewables in Australia*. https://solaremporium.com.au/blog/large-scale-batteries-supporting-renewables-in-australia/#:~:text=Energy%20Storage%20In%20Australia&text=Construction%20of%20sixteen%20large%2Dscale,under%20its%20Emerging%20Renewables%20program.

Solar Quotes. (2023, July 14). *Australian Solar & Battery Rebates, subsidies & incentives - 2023*. SolarQuotes. https://www.solarquotes.com.au/rebates-subsidies/#:~:text=Northern%20Territory,-Territorians%20can%20take&text=Home%20and%20business%20battery%20scheme,More%20information%20here.

SOMASUNDARAM, S., CHIAM, S. Y., & Ming Chou, L. (2020). *Energy Storage Systems Technology Roadmap for Singapore*. Retrieved from https://www.ntu.edu.sg/docs/librariesprovider60/publications/ess-technology-roadmap-singapore.pdf?sfvrsn=c91c9ae8_2

Song, D., Jia, B., & Jiao, H. (2022, October 10). *Review of Renewable Energy Subsidy System in China*. MDPI. Retrieved November 19, 2023, from https://www.mdpi.com/1996-1073/15/19/7429

Song, X., Huang, Y., Zhang, Y., Zhang, W., & Ge, Z. (2023, March 14). An Appraisal on China's Feed-In Tariff Policies for PV and Wind Power: Implementation Effects and Optimization. *Sustainability*, *15*(6). https://doi.org/10.3390/su15065137

Spherical Insights. (2023*). Japan Battery Energy Storage Market Size, forecast - 2032.* https://www.sphericalinsights.com/reports/japan-battery-energy-storage-market

SP Group. (2023). *Innovation*. Innovation. Retrieved November 19, 2023, from https://www.spgroup.com.sg/about-us/media-resources/energy-hub/innovation/sp-group-to-roll-out-singapore-s-first-large-scale-smart-water-metering-system

SP Group. (2023). *PowerGrid Overview.* SP Group. https://www.spgroup.com.sg/our-services/network/overview

Statista. (2023, April 5). *Australia: renewable energy capacity 2022*. Statista. Retrieved November 19, 2023, from https://www.statista.com/statistics/1248614/australia-renewable-energy-capacity/

Statista. (2023, September 27). *Electricity generation by type in South Korea 2022*. Statista. Retrieved November 19, 2023, from https://www.statista.com/statistics/884559/south-korea-electricity-generation-by-energy-source/

Stone, A. (2013, April 6). *Power man generates all his own electricity.* NZherald. https://www.nzherald.co.nz/nz/power-man-generates-all-his-own-electricity/T62CD3GOISRURUX4V2IMGRADTY/#:~:text=The%20Government%20takes%20the%20view,%2Din%20tariffs%2C%20or%20FITs

Strong, S. (2016, October 19). *Building Integrated Photovoltaics (BIPV).* Whole Building Design Guide. https://www.wbdg.org/resources/building-integrated-photovoltaics-bipv

Suchadra . (2023, August 5). *Renewable energy sources and their potential in India*. Enterclimate. https://enterclimate.com/blog/renewable-energy-sources-in-india/#:~:text=India%20has%20approved%2059%20solar,%2DII%20(648%20MW).

Tachev, V. (2022, May 12). *Renewable energy in the Philippines – current state and future roadmap.* Energy Tracker Asia. https://energytracker.asia/renewable-energy-in-the-philippines-current-state-and-future-roadmap/

Tachev, V. (2023, February 13). *South Korea's Energy Mix and Its 10th Basic Energy Plan*. Energy Tracker Asia. Retrieved November 19, 2023, from https://energytracker.asia/south-koreas-energy-mix-and-its-10th-basic-energy-plan/

Tachev, V. (2023, May 2). Malaysia’s energy transition: Challenges and opportunities. Energy Tracker Asia. https://energytracker.asia/malaysia-energy-transition/

TANAKA, M. (2023, January 30). Japan seeks more industrial rooftop solar with Rate Incentive. Nikkei Asia. https://asia.nikkei.com/Spotlight/Environment/Climate-Change/Japan-seeks-more-industrial-rooftop-solar-with-rate-incentive#:~:text=The%20Ministry%20of%20Economy%2C%20Trade,power%20generated%20on%20open%20land.

Tan, A. (2020). *Singapore to ramp up solar energy production to power 350,000 homes by 2030.* The Straits Times. https://www.straitstimes.com/singapore/environment/solar-energy-to-meet-4-of-singapores-energy-demand-by-2030-up-from-less-than-1

Tambunan, H. B., Hakam, D. F., Prahastono, I., Pharmatrisanti, A., Purnomoadi, A. P., Aisyah, S., Wicaksono, Y., & Sandy, I. G. (2020). *The challenges and opportunities of renewable energy source (RES) penetration in Indonesia: Case study of java-bali power system*. Energies, 13(22), 5903. https://doi.org/10.3390/en13225903

Tampubolon, A. P., Kurniawan, D., Arinaldo, D., & Vianda, F. (2021). Indonesia Energy Transition Outlook 2022 - IESR. https://iesr.or.id/wp-content/uploads/2021/12/IETO_2022_Outlook.pdf

Tarigan, E., Djuwari, & Kartikasari, F. D. (2015). Techno-economic simulation of a grid-connected PV system design as specifically applied to residential in Surabaya, Indonesia. Energy Procedia, 65, 90–99. https://doi.org/10.1016/j.egypro.2015.01.038

Transpower New Zealand Ltd. (2021). Opportunities and challenges to the future security and resilience of the New Zealand power system. Waikoukou, Wellington; Transpower New Zealand Ltd.

Trixl, A. (2023, July 20). The Renewable Energy Law Review: New Zealand. The Renewable Energy Law Review - The Law Reviews. https://thelawreviews.co.uk/title/the-renewable-energy-law-review/new-zealand

The Nation. (2023, February 8). *Thailand is promoting its green transformation to US investors.* The Nation. https://www.nationthailand.com/thailand/economy/40024739

The Straits Times. (2023, August 22). *Indonesia will ease solar power rules to unlock Green Investment*. https://www.straitstimes.com/asia/se-asia/indonesia-will-ease-solar-power-rules-to-unlock-green-investment

Tractus Asia. (2022, May 12). *Flex Fuel – Thailand's Renewable Energy Transition: Solar Energy And Beyond.* Tractus. https://tractus-asia.com/blog/flex-fuel-thailands-renewable-energy-transition/

Trang, Đ. (2023, May 26). *Solar Power in 2023: Which direction for businesses when "waiting for" pricing mechanisms?*Vietdata Research. https://www.vietdata.vn/post/solar-power-in-2023-which-direction-for-businesses-waiting-for-pricing-mechanisms

Trend Force. (2022, June 16). *Press Center*. Press Center | TrendForce - Market research, price trend of DRAM, NAND Flash, LEDs, TFT-LCD and green energy, PV. Retrieved November 19, 2023, from https://www.trendforce.com/presscenter/news/20220616-11256.html

TSUGE, M. (2022, January 14). Huawei Bolts into Japan with renewable power storage, chasing tesla. Nikkei Asia. https://asia.nikkei.com/Business/Energy/Huawei-bolts-into-Japan-with-renewable-power-storage-chasing-Tesla

United Nations Development Program. (2012). *Case Study Report: Thailand Energy Conservation Fund.* https://www.undp.org/sites/g/files/zskgke326/files/migration/asia_pacific_rbap/APRC-EE-2012-NCF-CaseStudy-Thailand.pdf

United Nations Framework Convention On Climate Change. (2018, December). *Singapore's Fourth National Communication and Third Biennial Update Report.* UNFCCC. https://unfccc.int/sites/default/files/resource/067382541_Singapore-NC4-BUR3-1-Singapore%20Fourth%20National%20Communication%20and%20Third%20Biennia.pdf

VELASCO, M. M. (2023, July 30). *Doe open to New Energy Storage Policy. Manila Bulletin. https://mb.com.ph/2023/7/30/doe-open-to-adjustments-on-energy-storage-policy*

Wang, X., Stern, R., Limaye, D., Mostert, W., & Zhang, Y. (2013). *Unlocking Commercial Financing for Clean Energy in East Asia*. World Bank Publications. https://doi.org/10.1596/9781464800207_Ch15

Wang, X., Stern, R., Limaye, D., Mostert, W., Zhang, Y. (2013, September). *Case Study: Thailand Energy Conservation (ENCON) Fund.* https://elibrary.worldbank.org/doi/10.1596/9781464800207_Ch15

WBCSD. (2022, November). *World Business Council for Sustainable Development* (WBCSD). https://www.wbcsd.org/contentwbc/download/15096/213804/1

Wood Mackenzie. (2023, July 17). *Australia leads global market for Battery Energy Storage Systems*. https://www.woodmac.com/press-releases/australia-leads-global-market-for-battery-energy-storage-systems/

World Bank Group. (2020, January). *World Bank Document*. World Bank Document. Retrieved November 19, 2023, from https://documents1.worldbank.org/curated/en/152501583149273660/pdf/Koreas-Energy-Storage-System-Development-The-Synergy-of-Public-Pull-and-Private-Push.pdf

World Nuclear News. (2023, January 12). *South Korea increases expected contribution of nuclear power : Nuclear Policies*. World Nuclear News. Retrieved November 19, 2023, from https://www.world-nuclear-news.org/Articles/South-Korea-increases-expected-contribution-of-nuc

Xu, M., & Stanway, D. (2022, August 25). *Explainer: The power crunch in China's Sichuan and why it matters*. Reuters. Retrieved November 19, 2023, from https://www.reuters.com/world/china/power-crunch-chinas-sichuan-why-it-matters-2022-08-26/

Xu, Y. (2023, March). *China, climate change and the energy transition*. Australia Strategic Policy Institute. Retrieved November 19, 2023, from https://ad-aspi.s3.ap-southeast-2.amazonaws.com/2023-03/China%2C%20climate%20change%20and%20the%20energy%20transition.pdf

Xu, Y. (2023, April 10). *CIMC Raffles delivers China's first floating solar power platform.* Upstream Online | Latest oil and gas news. https://www.upstreamonline.com/energy-transition/cimc-raffles-delivers-china-s-first-floating-solar-power-platform/2-1-1431673

Yen, H. (2023, July 20). *Vietnam needs US$135 billion for energy infrastructure until 2030*. hanoitimes.vn. https://hanoitimes.vn/vietnam-needs-us135-billion-for-energy-infrastructure-until-2030-324266.html

Yep, E. (2023, April 11). *South Korea revises 2030 target for greenhouse gas emissions*. S&P Global. Retrieved November 19, 2023, from https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/041123-south-korea-revises-2030-target-for-greenhouse-gas-emissions

Yutong, L., & Yelin, M. (2023, July 18). *Five Things Powering China's Energy Storage Boom*. Caixin Global. Retrieved November 19, 2023, from https://www.caixinglobal.com/2023-07-18/five-things-powering-chinas-energy-storage-boom-102076995.html

Zhou, F., Peng, L., & Li, J. (2022, September 5). China's 14th Five-Year Plans on Renewable Energy Development and Modern Energy System. Retrieved November 19, 2023, from https://www.efchina.org/Blog-en/blog-20220905-en

Zhou, Q. (2022, May 12). *China's Draft 2022 Encouraged Catalogue Signals New Opportunities*. China Briefing. Retrieved November 19, 2023, from https://www.china-briefing.com/news/china-proposes-to-expand-encouraged-industries-for-foreign-investment-the-draft-2022-catalogue

Zhu, Z., & Wijaya, A. (2023, February 13). *The future IS GREEN: Unlocking Indonesia's renewable energy potential*. East Ventures. https://east.vc/insights/the-future-is-green-unlocking-indonesias-renewable-energy-potential/#:~:text=From%20the%20current%20level%20of,net%20zero%20emissions%20by%202060

Zissler, R. (2023). *Renewable Electricity Procurement Guidebook (4th edition).* Battery Storage to Efficiently Achieve Renewable Energy Integration. https://www.renewable-ei.org/pdfdownload/activities/RE_Procurement_Guidebook_EN_2021.pdf

Appendix 1: Primary Research Questionnaire and Purpose of Design

1) To understand overall renewable landscape in Singapore

- How mature is Singapore's renewable energy development, both in terms of technology and scale as compared to other key players in the APAC region?
  (To help us better position Singapore among other APAC countries in terms of readiness of renewable development)

- Could you elaborate on the latest technologies currently being employed by Singapore in the realm of solar energy generation and storage? What are some of the weaknesses of those technologies and are there any emerging technologies that would serve to address those weaknesses?
  (To help us cross check Singapore's latest ESS technologies and R&D initiatives)

- What are the key challenges or bottlenecks faced by Singapore in solar energy storage? What are some key initiatives put forth to address those challenges?
  (To help us identify pain points)

- Do you think the Singapore government is doing enough to promote energy storage initiatives, in terms of both regulatory development and financial incentives to spur deployment of energy storage facilities?
  (To double check if there has been an issue from top down)

2) To understand the current solutions

- Based on our preliminary research, Singapore has been tackling renewable storage challenges through implementing VPP and installing large-scale batteries in Jurong Island? How would you evaluate those initiatives?
- Do you anticipate any challenges in implementing those initiatives or areas in the realm of Singapore's energy storage that have yet to be adequately addressed?
  (To evaluate the current solutions and see if there are holes we could poke and address)

3) To evaluate our solutions

- Based on the current landscape, our team is thinking of proposing a solution of installing batteries in commercial and residential buildings next to where solar panels have been installed. The batteries used could be recycled from electrical vehicle batteries for ease of implementation and sustainability purposes. We have seen successful case studies from Japan's EV batteries recycling and Australia's residential energy storage initiatives. The key reason behind this recommendation is to
  - Overcome challenges in geographical constraint.
  - Reduce transmission loss and reliance on batteries situated far away from the households and city centres.
  - More efficient energy management in case of energy supply shortage

- Collecting more accurate energy storage data for VPP to be more accurate in projecting energy needs

In your expert opinion, do you consider these initiatives to be viable for Singapore's energy storage needs? What are some foreseeable challenges associated with these solutions and do you have any constructive comments to enhance the robustness of our proposed recommendations?
(To evaluate our proposed solutions and see if there are any issues we need to better address)

4) Investment Considerations

- How investable do you think the above solution is at present, and in a few years' time (~3 years and 5 years moving forward) and why?
  (To evaluate our how feasible our proposed solutions are)

- How much does it cost to develop a battery for residential usage, commercial usage and industrial usage respectively, and how long does it take to break-even on those projects?
  (To gather some data for cost analysis)

- What are some key risks and mitigations for investing into ESS projects?
  (To understand risks and mitigations that we could address)

- Are there any key challenges you foresee that may affect the attractiveness and investability of Singapore's ESS market? How do you think the different stakeholders could work together to overcome these challenges
  (To better inform our top-down strategies)

Appendix 2: Responses to Primary Research

RP: Engineering Manager at Gurīn Energy
YM: Project Development, Enedis
PC: Business Development at Total Energy
AS: Principal Investments Analyst at Macquarie Capital

1) **To understand overall renewable landscape in Singapore**
   - **How mature is Singapore's renewable energy development, both in terms of technology and scale as compared to other key players in the APAC region?**

RP: Due to its geographical location, Singapore has only a few options for renewable energy development, in this case, the lowest-hanging fruit here is the Solar PV Renewable system.

In terms of technology, generally, Singapore has exhausted/explored most of the options available at the moment. Though I personally think the country can do more to impose the requirement for renewable energy implementation on buildings and available lands/reservoirs. Specifically on the technology of Solar PV systems deployed in the past few years, we see continuous improvement in the efficiency of the PV modules, therefore there will be more opportunities for repowering / upgrade of technologies on the existing PV systems in coming years.

In terms of the scales, from the point of view of the operator/ developer, Singapore does have a lot of room for scaling up renewable development, unlike other countries in the region.
This is due to strong grid stability conditions, exploration of battery systems deployment, as well as healthy over-capacity conditions on the power supply. We knew Singapore is ready to receive more renewable energy deployment.

YM: If you are referring to the development and deployment of renewable energy, Singapore really doesn't have a big hand to play. Solar is by far the biggest solution, and it is still going to be a small fraction of our renewable energy. Wind and geothermal are going to be trivial at best.

For solar, solar panels in the market are pretty standard stuff, although the specs have been improving over the years a little. Things like floating solar and solar panels on the side of buildings is where Singapore is a frontrunner in. Pretty understandable I must say as most places don't have a need to do these things.

In APAC, Singapore in my opinion is doing well in our capacity for renewable energy development but it's not something we can compare with say Vietnam and Malaysia and Laos, whose situations are all massively different. It may not be meaningful to draw such a comparison. But Singapore has the advantage in terms of how technologies are, given the research intensity in cutting-edge solutions (say TRL 6-7ish) – but actual deployments is another issue.

PC: 95% of Singapore's energy came from gas or fossil fuels and Singapore is undergoing a major transition to adopting more renewable energies. Unfortunately, Singapore faces significant limitations in the lack of wind and land. To resolve this, Singapore has been pushing forth rooftop solar and electricity imports, but had limited progress.

Other countries in SEA also do not have huge renewable energy adoption. In Indonesia, <5% of power comes from renewable energy. Malaysia mainly taps on hydro renewables and Vietnam suffers from poor top-down management in energy regulation.

AS: Due to its limited land resources and the availability of less expensive energy options, Singapore is having difficulty developing its renewable energy sector. This situation might alter, though, if banks decide to make investments in the future.

Furthermore, policies, which include measures like taxes to increase demand and incentives for infrastructure development, have a substantial impact on the supply and demand of renewable energy. In Singapore, businesses like Sembcorp and Keppel are actively involved in renewable energy efforts.

Instead of exclusively depending on government initiatives, private investments can hasten growth. The adoption of renewable technology by private firms is influenced by the state of the market and availability of funding. Due to the intense rivalry in the industry, profitability is a problem, but for private developers, access to cash and understanding of economical construction techniques are crucial. Private participation may also be discouraged by high entrance fees, which can cost over a billion USD to build just one megawatt. Overall, there are a few companies in the market, but they are not sufficiently advanced to make the development workable.

- **Could you elaborate on the latest technologies currently being employed by Singapore in the realm of solar energy generation and storage? What are some of the weaknesses of those technologies and are there any emerging technologies that would serve to address those weaknesses?**

RP: Solar energy technology is highly interrelated to PV module technology. Currently, most Solar PV projects in Singapore are based on p-type polycrystalline, and p-type Mono PERC, while people are now using n-type PERC as well as n-type ABC modules, and moving forward with HJT modules in the near future.

For storage, what we have now is just Jurong Island 100MW BESS deployment based on 280Ah battery cells, next year onwards the mainstream manufacturing will be going with 314Ah battery cells, as well as 340Ah in the near future.

- **What are the key challenges or bottlenecks faced by Singapore in solar energy storage? What are some key initiatives put forth to address those challenges?**

  RP: Land shortage is currently the most significant bottleneck. Singapore is trying to adust this by utilising all the roof surfaces and lands/reservoirs.

  PC: PC: Due to low renewable energy capacity, particularly in solar, the growth potential of batteries is still constrained. Banks are hesitant to lend money to electricity businesses due to their lack of maturity. Commercial viability and project feasibility are important requirements for bank financing.

- **Do you think the Singapore government is doing enough to promote energy storage initiatives, in terms of both regulatory development and financial incentives to spur deployment of energy storage facilities?**

  RP: It could be better. Some countries made it compulsory to have solar PV deployment on their buildings.

  PC: Singapore government is willing to provide revenue support. However, the bidding process is competitive. In terms of subsidies, Singapore has granted a low interest rate for renewable energy project and banks are heavily involved to provide financing. For banks to consider financing a renewable project, the project needs to be commercially and financially viable. Pure green movement does not lead to investment.

2) To understand the current solutions

- Based on our preliminary research, Singapore has been tackling renewable storage challenges through implementing VPPs and installing large-scale batteries in Jurong Island? How would you evaluate those initiatives?

  RP: It is not new, and unavoidable. People in Europe have been doing it for years. The large-scale battery deployment in Jurong Island is intended for different purposes, not specifically to manage the intermittency of the renewable supply. That initiative is needed, but it is not essential given Singapore's grid condition.

  YM: There are two issues with this interpretation. The first is that a VPP is not a storage thing it’s an idea. The idea is that through distributed resources, the resources can mimic the functional output of a power plant. These resources can include small generators, solar panels, battery storage etc. it doesn’t really matter as long as to the grid, it feels like a power plant instead of an assortment of stuff. The second is that it seems like energy storage is deployed for renewable energy storage. This is only partially true (in fact, I'll say less than partially). Singapore doesn't have a big share of renewable energy (~<5%) and we face less challenges than countries like Germany who face a lot of storage problems with huge renewable energy proportions. For Singapore, I expect at least as many problems to come from demand side and grid congestion as compared to renewable energy eneration. In a sense that energy Storage is a solution fundamentally to solve the issue that energy is not generated and used at the same space and time, and that is not exclusive to solar generation.

For VPP and large-scale batteries deployed, they are definitely good initiatives. I have not done evaluations as to whether they are sufficient. I also do not know the business use of those batteries in the grid context, which is another thing (i.e., whether they are open participants in the energy market, or are they balancing and ancillary services that are under Singapore Power). Now you see what I mean by energy topics getting complicated pretty fast – now we are entering the arcane world of energy markets.

I think that the concept of installing batteries in residential buildings is an interesting one and there are a lot of things to explore, but there is a lot of work you need to be prepared to do to go through technicalities if you all want to take this project deep enough to be a legitimate evaluation as a potential energy solution. That's why I asked about how many MCs or how long you have to do this because if you are working on a short time frame on a steep learning curve, you will need to control the scope and depth of this project.

At this juncture, I think it is important to write down and keep a record of key assumptions as you think of it. For example, 3 of which come off my mind when I had a brief look through:

Assumption 1: Energy storage of renewable energy in Singapore is a problem.
Assumption 2: Recycled batteries can be used in residential buildings.
Assumption 3: Energy losses in transmission and distribution is significant.
This way, it makes it clear what you know, and what you think you know. Not all assumptions can be well verified at the end of the day, but it's important to be aware. Simple questions may not have simple answers.

PC: Batteries are expensive. However, the growth trajectories do not seem to be optimistic as there has been very limited growth potential for batteries. Banks are reluctant to finance power companies as there's limited return and Singapore's renewable landscape is simply vast different from countries like Australia with drastically more solar energies.

- Do you anticipate any challenges in implementing those initiatives or areas in the realm of Singapore's energy storage that have yet to be adequately addressed?
  (To evaluate the current solutions and see if there are holes we could poke and address)

RP: It is not new, I don't see there will be an issue in implementing it, given the demand for renewable largely exceeds the supply available.

PC: Besides limited land and solar resources, we are good at transparent policy, well developed legal framework, good for investment

3) To evaluate our solutions

- Based on the current landscape, our team is thinking of proposing a solution of installing batteries in commercial and residential buildings next to where solar panels have been installed. The batteries used could be recycled from electrical vehicle batteries for ease of implementation and sustainability purposes. We have seen successful case studies from Japan's EV batteries recycling and Australia's residential energy storage initiatives. The key reason behind this recommendation is to
    - Overcome challenges in geographical constraint.
    - Reduce transmission loss and reliance on batteries situated far away from the households and city centres.
    - More efficient energy management in case of energy supply shortage
    - Collecting more accurate energy storage data for VPP to be more accurate in projecting energy needs

In your expert opinion, do you consider these initiatives to be viable for Singapore's energy storage needs? What are some foreseeable challenges associated with these solutions and do you have any constructive comments to enhance the robustness of our proposed recommendations?

RP: Yes, technically in the future. However, I don't see how it will be commercially viable, as there isn't a difference in electricity for different times in Singapore residences and commercial buildings. Energy supply into BESS is priced the same as exported energy from BESS - Round Trip In-efficiency. On top of that, there isn't any leasing model which is available for grid-support facilities. The reuse of EV batteries is a good idea, indeed, 60% remaining capacity must be up-cycle for better use in the industry, it could be a booming industry in the next 5 years.

PC: The main difficulties are the commercial feasibility of solar technologies, which is impacted by things like electricity costs and implementation expenses. It is also important to consider how many rooftops there are in Singapore and what percentage of those are appropriate for rooftop solar. (It is worth looking into Australia's case and businesses like SKYE Renewables and Solar AI Technologies). Large-scale utility projects are constrained by land restrictions, although initiatives like JTC's are noteworthy. The government has advanced rooftop solar initiatives, providing a good example.

AS: Since renewable energy projects sometimes call for substantial financial investments, one potential obstacle would be the absence of investor demand for such projects. In addition, the sensibility of developers' abilities to carry out these projects is crucial taking into account variables like permit. Finding out whether these investments offer decent returns is another important factor, with factors like the Internal Rate of Return (IRR) and the speed at which capital can be recovered reflecting the level of risk involved. Lastly, it is crucial to identify potential risks, comprehend worst-case situations, and thoroughly assess the counterparty's capacity to fulfil financial commitments to investors.

To enhance the robustness of the proposed solution. One feasible option is to capitalise on customer demand by establishing a smart metre system integrated with battery storage. This idea leverages pricing dynamics, in which customers are prepared to pay more during periods of high demand and less during periods of low demand. Energy providers can increase rates at peak times and subsequently arbitrage energy costs by utilising battery storage technology, providing lucrative potential for battery investments. A further suggestion would be to investigate methods that encourage the more effective use of energy resources already at hand, hence lowering a nation's dependence on renewable energy sources.

How practical is smart metering in Singapore? How can we incentivise market?

AS: We need to analyse several factors for investment in smart metres in Singapore. Firstly, government policy is needed to liberate energy market space and allow energy trading. Secondly, we need to provide opportunities for companies to make money by selling renewable energy during peak time and through arbitrage. Both factors are not available right now in Singapore. The U.S. is doing great by liberalising electricity markets.

Since a large portion of renewable energy would be imported in the following decades. Is there a need to store the energy which was imported?

PC: Singapore does not need to store energy imports from overseas. Solar works 25% of time and requires storage to operate for 75% of time. Solar is limited to sun shining and its supply level is very volatile. When we import renewable energy from overseas plants the battery is next to that plant from other countries. When we import energy - meaning we get batteries from other countries, Solar energy is already stored in that battery.

4) Investment Considerations

- **How investable do you think the above solution is at present, and in a few years' time (~3 years and 5 years moving forward) and why?**

AS: In terms of renewable energy, costs are always concerns for investors. In certain geographies, financing is easier. Still need to convince people to invest using the framework mentioned, which includes questions about demand, execution and returns. As capital for supplies has decreased, the demand side is very important and we need to get the right customers.

- **How much does it cost to develop a battery for residential usage, commercial usage and industrial usage respectively, and how long does it take to break-even on those projects?**

- **What are some key risks and mitigations for investing into ESS projects?**

  PC: Cost could become a big thing. Government needs to step in to subsidise and make ESS projects commercially viable.

- **Are there any key challenges you foresee that may affect the attractiveness and investability of Singapore's ESS market? How do you think the different stakeholders could work together to overcome these challenges**

  PC: In the realm of Bank financing, government entities (such as GIC, Temasek, etc.) have to back up this kind of project. When projects go bust, the government pays back. Investment through Bayfront infrastructure may be possible. Another incentive for storage development would be to ask banks to reach a target of financing in RE.

  AS: Investors of renewable energy do not perceive Singapore as a big market, but Singapore is seen as a trusted and solid market player for investors due to the government's commitments for renewable energy. Singapore is lagging behind Korea and Japan in terms of incentives. In the next five years, people care more about the demand side and getting the right customers as the supply side is saturated.

- **From your experience, what are some trends you see in the renewable energy sector? Is it being more widely adopted and are costs getting cheaper to a point where it is comparable to conventional energy?**
  PC: RE 100: company committed to decarbonisation through electricity source; willing to pay premium for energy source