Regulatory/Market Settings to Support Greater Electrical Energy Storage Development for Sustainable and Socially Responsible Electricity Sector CO2 Emissions Reductions in APEC Economies

APEC Energy Working Group

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Contents

List of acronyms and abbreviations

Acronym	Description
ADB	Asian Development Bank
APEC	Asia-Pacific Economic Cooperation
ARENA	Australian Renewable Energy Agency
ASEAN	Association of Southeast Asian Nations
BESS	Battery Energy Storage System
CAISO	California Independent System Operator
CAES	Compressed-air energy storage
CIS	Capacity Investment Scheme
CO2	Carbon dioxide
CSPG	China Southern Power Grid
DFAT	Department of Foreign Affairs
DOE	Department of Energy
EES	Electrical Energy Storage
EGAT	Electricity Generating Authority of Thailand
EWG	Energy Working Group
FCAS	Frequency Control Ancillary Services
FERC	Federal Energy Regulatory Commission
FIT	Feed-in-Tariff
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt-hour
IPP	Independent power producers
IRA	Inflation Reduction Act
ISO	Independent System Operator
KW	Kilowatt
KWh	Kilowatt-hour
LCOE	Levelized cost of energy
LTESA	Long Term Energy Service Agreement
MIDA	Malaysian Investment Development Authority
MyRER	Malaysia Renewable Energy Roadmap

MW	Megawatt
MWh	Megawatt-hour
NEA	National Energy Authority (Papua New Guinea)
NEP	National Energy Policy
NEM	National Electricity Market
NEROP	National Electrification Roll Out Plan
NGR	Non-generator resource
NOVA-VPP	Net Offset Virtual Aggregation Virtual Power Plants
NTEM	Northern Territory Electricity Market
PPA	Power purchase agreement
PPL	PNG Power Limited
PRLCE	Peer Review on Low Carbon Energy Policies
PSH	Pumped Storage Hydropower
PV	Photovoltaic
RE	Renewable Energy
RTO	Regional Transmission Organization
SESB	Sabah Electricity Sdn Bhd
SESCO	Syarikat SESCO Berhad
SGCC	State Grid Corporation of China
SHS	Solar Home System
SMP	System Marginal Price
SOE	State-owned enterprise
SPP	Small Power Producer
TNB	Tenaga Nasional Berhad
VPP	Virtual Power Plant
VRE	Variable Renewable Energy
VSPP	Very Small Power Producer
WEM	Wholesale Electricity Market in Western Australia

Glossary of technical terms and concepts

Term	Description
Ancillary services	The additional services that energy storage systems can provide to support the stability and reliability of the power grid.
Behind-the-meter	Behind-the-meter energy refers to the power that is produced and consumed on-site.
Capacity market	A system designed to ensure that electricity supply always meets demand.
Curtailment	Energy curtailment refers to the deliberate reduction in energy production due to transmission or storage constraints.
Discharge time	The amount of time it takes for that device or system to discharge completely.
Dispatch signals	The signals that tell the fleet of existing generation and storage assets when and how to operate.
Energy dispatch	The process of scheduling and controlling the production of electricity from various power plants to meet the demand.
Energy spot market	A system where the price of electricity is calculated and traded in real-time.
Feed-in tariff	A policy tool designed to promote investment in renewable energy sources. It usually means promising producers of energy — such as solar or wind energy — an above-market price for what they deliver to the grid.
Firming technologies	Methods used to smooth out the peaks and fill in the gaps from variable renewable energy.
Grid flexibility	A power system's ability to quickly adapt to changes in electricity supply and demand.
Grid stability	The balance between the production and consumption of electricity within an electrical grid.
Investment signal	Signals that tell investors when to invest in building generation and storage assets to ensure future market needs are met.
Levelized cost of energy	The levelized cost of energy of an energy-generating asset can be thought of as the average total cost of building and operating the asset per unit of total electricity generated over an assumed lifetime.
Merit order dispatch system	A method used in the electricity supply industry to determine the order in which power plants are used to meet the demand for electricity.
Response time	The response time of an energy storage system refers to the time it takes for the system to provide energy at its full rated power.
Round trip efficiency	The ratio between the energy supplied to an energy storage system and the energy retrieved from it.
Single buyer model	In this model, a state-owned enterprise or a publicly controlled institution

Term	Description
	acts as the major power producer and the single buyer or monopsonist of electricity from private power producers.
Storage capacity	The amount of energy that can be stored in an electrical energy storage device or system.
Utility-scale electrical energy storage	A method used for storing energy on a large scale within an electrical power grid.
Vertically integrated electricity market	A market structure where a single company controls both the generation and distribution of electricity.
Whole electricity market	A market system that enables the purchase and sale of electricity through bids to buy and offers to sell

Executive Summary

Electricity generation from fossil fuels contributes significantly to global greenhouse gas (GHG) emissions, exacerbating climate change impacts across the globe. An important component of international commitments to limit GHG emissions is the need to rapidly transition to zero/low-carbon electricity grids.

The Asia-Pacific Economic Cooperation (APEC) region plays a major role in the global energy sector, accounting for 56% of world energy demand, 58% of world energy supply, and 68% of world electricity generation. With most of the energy demand in the APEC region derived from fossil fuels, the commitments of APEC member economies in transitioning towards using clean energy sources, especially for electricity generation, is significant.

Among all renewables, variable renewable energy (VRE) sources, including solar and wind, are expected to see the largest growth in terms of capacity, highlighting the importance of investing in electrical energy storage (EES) technologies to maintain reliable electricity supplies given fluctuations in VRE generation and demand.

This project aligns with the 2014 APEC statement on doubling aggregate share of renewables in the APEC energy mix by 2030, by encouraging investment in EES to ensure security of electricity supply in APEC economies. It also aligns with APEC's 2011 energy resiliency statement, as EES enables power distribution even during disruptions caused by disasters. Building on a comprehensive desk review of academic and grey literature related to EES and APEC member economies' energy markets, the project developed assessment criteria for market settings that help promote EES investment before applying it to 3 APEC member economies – Malaysia; Papua New Guinea; Thailand – with a focus on identifying information and policy gaps, as well as economy specific options for expanding EES in each economy.

Project findings were validated through individual ground truthing workshops with each of the above noted economies, as well as a main project workshop drawing on broader APEC member economies and energy market experts.

Assessing good practice within the APEC region

An assessment for good practices in domestic EES market settings was developed through looking at the experiences of three APEC member economies which have made significant progress in promoting EES investments: Australia; People's Republic of China (China); United States. Despite each having unique market structures and backgrounds, the study identified shared approaches in market settings that encourage EES investments across these economies. Three key criteria for effective market environments emerged:

- **Regulatory frameworks:** Flexible policies to signal EES growth, clear and consistent regulations, stakeholders' engagement, and support for diverse range of EES technologies.

- **Financial Support:** Government investment and co-investment and other financial incentives to lower costs and risks for EES projects.
- **Market Mechanisms:** Strong, long-term investment signals, energy arbitrage opportunities, and participation in ancillary service markets to enhance profitability.

Assessment of domestic EES markets in target economies

Based on the criteria of good practices in domestic EES market settings, the report applied the lessons learned from the case studies to investigate the domestic EES market settings in Malaysia; Papua New Guinea; Thailand.

Malaysia

- Malaysia's energy market is centrally regulated by the Ministry of Energy and Natural Resources. The electricity sector has both public suppliers and private independent power producers for generation, while transmission and distribution remain monopolized by the state-owned Tenaga Nasional Berhad. EES technology, though still emerging, is used to manage excess solar energy and reduce peak electricity costs.
- The market structure and policy settings for EES in Malaysia is still evolving. There is a need from the private sector for more information on future market demand and available financing to support EES development.
- Malaysia can strengthen its EES investment landscape by refining regulatory frameworks to boost investor confidence, such as providing specific capacity targets and timelines for EES deployment. Leveraging existing hydro infrastructure for PSH, conducting economic case studies to signal project viability, and implementing targeted financial incentives — including grants, rebates, and performance-based credits — would help address the high upfront costs of EES.

Papua New Guinea

- Papua New Guinea has vast natural resources but faces major energy challenges due to its complex geography, which includes over 600 islands and rugged terrain. This has limited grid expansion and electricity access, especially in remote and rural areas. The Electrification Roll Out Plan aims to achieve 70% electrification by 2030 and full access by 2050, with a focus on renewable energy sources such as solar, wind, and hydro, alongside traditional fossil fuels.
- EES technologies are emerging in Papua New Guinea, with supportive policy and market frameworks currently being fine-tuned by the National Energy Authority to enhance the potential for EES development. These efforts are expected to facilitate investment pathways and encourage broader adoption of EES solutions in the energy sector.

- To promote EES development, Papua New Guinea could integrate energy storage into its National Electrification Strategy, creating a unified policy that supports both grid-scale and off-grid storage solutions. Introducing clear EES targets and supportive policies for storage in underserved areas would enhance energy reliability and support renewable integration. Additionally, the government could offer targeted financial incentives such as subsidies, grants, or tax exemptions to reduce financial barriers and attract private investment in EES, along with subsidies specifically for off-grid battery systems to make energy storage more affordable in remote communities.

Thailand

- Although Thailand has abundant natural gas resources, the economy relies heavily on imported fuels like crude oil, highlighting the need for energy independence. Commitments to climate goals domestically and internationally further strengthen Thailand's focus on renewable energy.
- EES technologies, especially Battery Energy Storage Systems and Pumped Storage Hydropower (PSH), are central to Thailand's vision for energy resilience and cost reduction. As a regional leader in PSH capacity, Thailand is well-positioned to expand smart infrastructure and EES projects, enhancing energy independence.
- Thailand can strengthen market and policy settings to promote EES investment by expanding direct financial incentives specifically for EES, such as subsidies and tax exemptions, would encourage private sector engagement in standalone and integrated storage solutions. Additionally, expanding the FIT quota for solar-plus-storage projects and providing clear guidelines for energy arbitrage opportunities would offer stable revenue streams, attracting larger-scale investments in Thailand's evolving EES market.

Recommendations for APEC member economies

Drawing on insights from the case studies of Australia; China; United States, as well as the assessments of Malaysia; Papua New Guinea; Thailand, the report outlines recommendations for propose high-level recommendations for APEC member economies to strengthen their market settings for EES development and investment. These recommendations are rooted in the three criteria of good market settings: regulatory frameworks, financial support, and market mechanisms.

1. Introduction

Electricity generation from fossil fuels such as coal and natural gas contributes significantly to global greenhouse gas (GHG) emissions, exacerbating climate change impacts across the globe. An important component of international commitments to limit GHG emissions, such as the 2015 Paris Agreement and the 2021 Glasgow Climate Pact, is the need to rapidly transition to zero/low-carbon electricity grids. The worldwide acceleration in the use of renewables-based generators (such as wind and solar-based systems) is a part of this transition. The accelerated uptake of renewable energies is important for not only meeting existing energy requirements, but also for meeting future energy needs as electrification increases across economies.

The Asia-Pacific Economic Cooperation (APEC) region is a major economic hub and global player in the energy sector. In 2021, the 21 APEC member economies accounted for about 38% of the global population and 62% of the global nominal gross domestic product (GDP) in 2021 (APEC 2022). In 2022, they accounted for 56% of world energy demand, 58% of world energy supply and 68% of world electricity generation (APEC 2022). Fossil fuels are the dominant energy source in most APEC member economies, making 86% of total primary energy supply and 75% of electricity generation (APEC 2023). If APEC economies take a business-as-usual approach, over 80% of the region's primary energy demand in 2050 is forecast to still be met by fossil fuels (APEC 2019).

Dependency on fossil fuels heightens concerns involving environmental impacts, insufficient production, and volatility in the world oil market due to political instability. Since 1990, the overall oil demand in the APEC region has increased more significantly than oil production (APEC 2013). The APEC region continues to be a net energy importer with multiple member economies importing oil from the Middle East, exposing the region to possible supply shocks (APEC 2023).

1.1. Increase renewable energy use in APEC

APEC member economies have shown strong commitment to increasing the use of clean energy sources. In 1990, APEC launched the Energy Working Group (EWG) which sought to build the capacity of members to strengthen domestic and regional energy security and lower the carbon intensity of energy supply and use across the region. In 2014, APEC member economies announced a goal to double the share of renewables in the energy mix between 2010 and 2030 (APEC 2023). Between 2010 and 2020, the share of modern renewable energy (RE) increased from 6% to almost 9.5% (APEC 2023).[1]

The acceleration in the adoption of RE is driven by APEC member economies' expanding electricity sectors. In 2020, RE generated 24.7% of electricity across APEC economies – up from only 15.6% in 2010. Figure 1 shows the expansion of

[1] Excluding traditional biomass which is typically relied on in emerging economies for household energy needs and is associated with negative health outcomes.

the renewable share in the electricity mix. Currently, APEC is ahead of its schedule to double the share of RE by 2030.

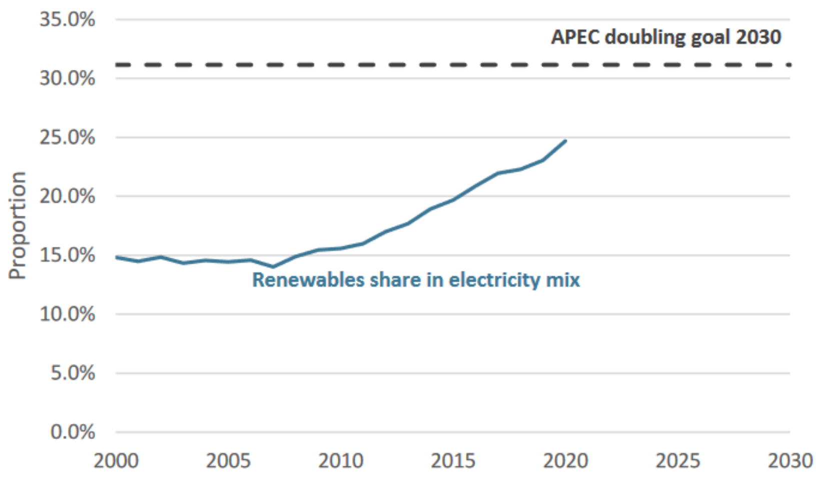

Figure 1: APEC modern RE share in the electricity mix (2000-2020)

Variable renewable energy (VRE) sources, including solar and wind, are expected to see the largest growth in terms of capacity (APEC 2019). The penetration of VRE highlights the importance of electrical energy storage (EES) technologies in ensuring electricity system flexibility and reliability as they can store excess energy that would otherwise be curtailed. EES can then discharge stored energy for use when required. In addition, as thermal generation has traditionally provided ancillary services – essential support services to ensure the stability, reliability, and efficiency of the electrical grid – the transition away from thermal generation to RE may pose some challenges to the grid. EES technologies, such as batteries, can provide these ancillary services, supporting the green energy transition.

The adoption of market settings to encourage the use of EES technologies, including pumped storage hydropower (PSH), has been limited in many APEC member economies. According to the *APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply* prepared for the APEC EWG in 2022, all APEC member economies except for Brunei Darussalam; Hong Kong, China; Singapore had significant potential for installing PSH systems (APEC 2022). However, neither PSH, nor other EES technologies, appears to be a major consideration in APEC economies.

This current project builds on and extends this previous work. It focuses on the economics of EES technologies, specifically the domestic markets for EES in APEC member economies.

1.2. Project objectives

The project sought to assist APEC members to establish domestic market settings to encourage investment in EES, including both grid-scale and behind-the-meter systems. In doing so, it supports members in the transition towards zero/low-carbon electricity grids in the longer term and their commitments under the Paris Agreement.

The project undertook a detailed investigation into EES related market settings in Malaysia; Papua New Guinea; Thailand. These three APEC economies previously participated in the Peer Review on Low Carbon Energy Policies (PRLCE) project. The detailed investigation included an assessment of existing EES-related market settings and EES-related information needs in each target economy, complemented by a review of good EES market settings practice among APEC economies. A particular focus was placed on PSH as part of this assessment.

1.3. Approach to delivery

The project was guided by the following research questions:

1. What are the **criteria** for good practice relating to EES market settings in APEC economies?
2. What are the **assessments of domestic EES markets** in Malaysia; Papua New Guinea; Thailand against the criteria of good practice relating to EES market settings?
3. What are the **information needs/gaps** that need to be addressed to inform market settings that are conducive to EES investments in Malaysia; Papua New Guinea; Thailand?
4. What are the **economy-specific options** for changes that could be made to EES market settings in Malaysia; Papua New Guinea; Thailand to encourage additional EES investments?

The primary method employed a desk review of APEC documents, and the broader academic and grey literature related to EES and APEC member economies' energy markets. Preliminary findings were initially validated through ground truthing workshops with key energy experts from government and civil society in Malaysia; Papua New Guinea; Thailand. These findings were then validated in a final project workshop that included representatives from across APEC and other international energy experts.

1.4. Report structure

Section 2 presents an overview of good EES market settings practice among APEC economies with extensive EES – Australia; China; United States.

Section 3 builds on the case study analysis and identifies the criteria for assessing good market settings for EES in APEC member economies, related to regulatory frameworks, financial support and market mechanisms.

Section 4 details the technical assessment of current electricity sector market settings in Malaysia; Papua New Guinea; Thailand. The assessment identifies good practices and policy gaps with regards to facilitating EES investment in these target economies.

Section 5 highlights information needs and gaps that need to be filled to inform further EES investments in Malaysia; Papua New Guinea; Thailand. It also suggests economy specific options for changes that could be made to EES market settings in Malaysia; Papua New Guinea; Thailand to encourage additional EES investment.

Section 6 provides recommendations for all APEC member economies to strengthen their market settings for EES development and investment

2. Good practice relating to EES market settings in APEC economies

In reviewing examples of good practices related to EES market settings, it is important to acknowledge the significant diversity across the 21 APEC member economies. APEC member economies stretch over four continents and are home to more than 2.9 billion people (DFAT, n.d.). APEC comprises a wide spectrum of economies, encompassing developed economies, emerging economies, and developing economies. Similarly, economic growth rates across APEC member economies display significant disparities. APEC member economies operate under distinct market conditions and levels of government ownership.

As affirmed in the Bangkok Goals on Bio-Circular-Green Economy, APEC strives toward "[ensuring] diversity and inclusion in [APEC's] efforts to address climate change" (APEC 2022). In assessing EES market settings in different APEC member economies and providing recommendations to support them in their transition to zero/low-carbon electricity grids, this diversity is acknowledged. There is no one-size-fits-all solution to establishing domestic market settings that encourage investments in EES. For initiatives to be beneficial, they must be inclusive, flexible and tailored to each member's context.

2.1. Understanding good practice of EES

Australia; China; United States stand out among all APEC member economies as compelling case studies for evaluating favorable market settings for EES, especially PSH, for two reasons:

- **They have achieved notable successes in facilitating investments in EES technologies, especially PSH**. All three economies have made significant commitments in integrating RE sources, particularly wind and solar, into their energy mix. These three economies are among the top developers of PSH in the region (Global Energy Monitor n. d.).
- **They display diverse characteristics and experiences in the energy sector and approaches to EES market settings**. Australia; China; United States showcase a diverse range of energy market structures, characterized by varying degrees of liberalization. Following from their energy market structures, each pursue different strategies in setting the domestic EES markets. These approaches encompass the extent of government involvement, and the specific policies designed to stimulate investments in EES.

2.1.1. Assessment of good practice case studies

This section provides further detail on the market settings that have facilitated the growth of EES in Australia; China; United States. There is no "cookbook" recipe for success in domestic EES market settings. As such, it is necessary that the report first engages with understanding the market context of each economy's energy sector.

Within each economy context, consideration is given to:

- **Direct government involvement** – this includes direct government interventions through the forms of mandates and targets to develop EES capacity. These policies directly drive investments in EES.
- **Government financial support** – this includes financial support for EES investment and installation, such as circumstances where government money is spent to cover part or all the up-front cost of building EES capacity (e.g., government investments or co-investments, grants and subsidies). It can include tax rebates and other incentive schemes to incentivize EES development. Financial supports from the government are crucial in encouraging investment in EES technologies, as these technologies often require a high upfront investment.
- **Dispatch signals** – the signals that tell the fleet of existing generation and storage assets when and how to operate. Dispatch signals tell which markets from which storage assets can generate revenues and how storage assets are priced. Dispatch signals are important because they provide potential or existing EES investors with information about their revenue prospects, which is crucial in investment decision-making.
- **Investment signals** – longer-term signals that tell investors when to invest in building generation and storage assets to ensure future market needs are met. Offtake agreements or power purchase agreements (PPA) which last several years are examples of investment signals. Like dispatch signals, investment signals inform investors about possible revenue opportunities. However, due to their long-term and structural nature, investment signals inform investors regarding how certain those revenue opportunities are.
- **Ancillary service markets** – markets within the broader energy sector where EES systems provide essential support services to ensure the stability, reliability, and efficiency of the electrical grid. These services are considered ancillary because they are secondary to the primary goal of delivering electricity but are vital for grid operations. It is important for storage electricity to be fairly remunerated in these ancillary service markets because they provide EES investors with new channels of revenue creation and act as an investment incentive.

2.2. Australia

Key findings – Australia
• Australia has a vast and diverse geography with abundant energy resources, including fossil fuels and renewable energy sources like wind and solar. The economy has the potential to become a "renewable energy superpower" due to its high-quality wind and solar resources and a growing demand for clean and reliable power.
• Australia has committed to reducing carbon emissions by 43% from the 2005 level by 2030 and achieve net-zero emissions by 2050. Decarbonizing the electricity sector is key to meeting this commitment. To support the transition to VRE sources, Australia needs rapid development of EES, with a substantial increase in energy storage capacity by 2050.
• Australia has three wholesale electricity markets with separate regulatory arrangements: the National Electricity Market (NEM), Wholesale Electricity Market in Western Australia (WEM), and Northern Territory Electricity Market (NTEM).
• Australian governments have adopted a relatively minimal approach to mandating the adoption of EES technologies. Government intervention focuses on setting EES capacity targets and providing financial support including grants, subsidies, tax credits and investments in both large-scale and small-scale EES projects.
• EES investors in Australia earn revenues primarily through energy arbitrage in wholesale energy markets as well as by providing ancillary services for a price. Eligible ancillary services include frequency regulation, voltage support and black start capability.
• Australia faces gaps in regulatory frameworks, market mechanisms, and incentives, which could be addressed to encourage EES investment and development.

Australia has a vast and diverse geography. It is abundant in both fossil fuels and renewable energy sources. With high-quality wind and solar resources and a growing energy demand for clean and reliable power, Australia has the potential to be a "renewable energy superpower" (DCCEEW 2024a). Despite the abundance of RE sources, coal still accounted for around 60% of energy production in Australia in the 2022-2023 financial year (DCCEEW 2024b) due to significant past government investment in coal fired power. However, this legacy coal fleet is reaching its operational lifespan. According to the Australian Energy Market Operator (AEMO)'s biannual integrated system plan (ISP), a portfolio of renewables and firming technologies such as batteries and PSH will be the best and cheapest way to replace gas-powered generation (AEMO 2024a). In recent times there has been steady growth in power drawn from renewables, as shown in Figure 2. In the 2022-2023 financial year, around 34% of Australia's total electricity generation was from RE sources – including solar (15.3% of total generation), wind (11.4%) and hydro (6.1%) (DCCEEW 2024b).

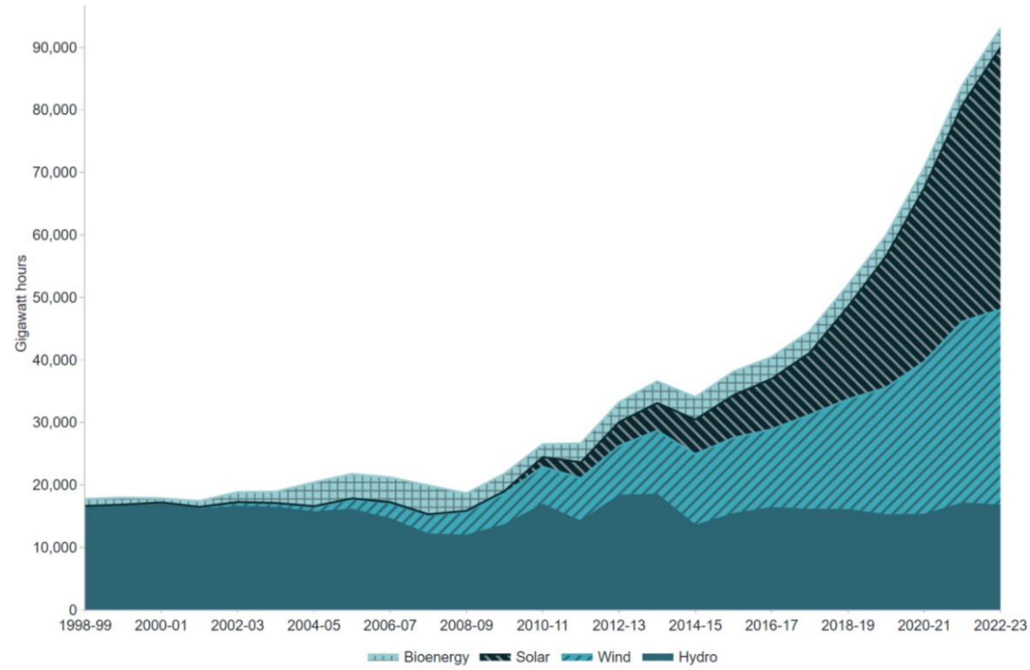

Figure 2: Australian electricity generation from renewable sources in gigawatt hours from 1998-99 to 2022-23.

The expansion of RE generation reflects Australia's goals to reduce carbon emissions by 43% by 2030 from the 2005 level and to achieve net zero by 2050, as committed in the *Climate Change Act 2022* (DCCEEW 2024c). Adoption of RE also reflects the falling price of wind and solar which are already cheaper than fossil fuel generation (Graham et. al. 2023). Given the rapid increase in energy demand, moving towards variable RE sources requires the fast development of EES technologies.

Australia has vast potential for EES development, especially PSH. According to the Bluefield Pumped Hydro-electric Storage Atlas developed by researchers at the Australian National University, Australia has more than 22,000 potential PSH locations (Blakers and Nadolny 2023).

Although other EES technologies are available in Australia, PSH is the most common and mature. Australia has three existing major PSH systems connected to the domestic electricity grid – Wivenhoe, Tumut 3, and the Shoalhaven Scheme, amounting to 1.6 gigawatt (GW) (WSP 2022). Australia also uses Battery Energy Storage Systems (BESS) for grid-scale applications. Examples of grid-scale BESS include the Victorian Big Battery Project near Geelong in Victoria or the Hornsdale Power Reserve in South Australia. A few years ago, large-scale BESS was not yet economically viable (Banfield et. al. 2019). Since then, there has been significant BESS deployment, allowing short-duration batteries to be economic in some jurisdictions in Australia. BESS plays a different role in the grid as they provide storage for minutes up to hours, in contrast to PSH which stores energy for hours up to weeks (see Annex A). Gilfillan and Pittock (2022) use the levelized cost of energy (LCOE), which considers all major cost elements for each technology, and finds that PSH is currently the second cheapest grid-suitable EES technology after conventional compressed-air energy storage (CAES). CAES may have greater environmental impact than PSH, as some CAES systems burn natural gas to release the stored energy and cause GHG emissions (Gilfillan and Pittock 2022).

In terms of small-scale and residential storage, many households and businesses in Australia have adopted BESS. These small-scale batteries can be installed in homes with solar systems to store energy for later use. In 2022, 47,100 residential EES systems were installed (Carroll 2023). Popular technologies for BESS include lithium-ion and sealed gel.

2.2.1. Understanding the Australian energy market

There are three wholesale electricity markets in Australia: the National Electricity Market (NEM) which covers eastern and south-eastern states and territories (the Australian Capital Territory, New South Wales, Queensland, South Australia, Tasmania and Victoria), the Wholesale Electricity Market in Western Australia (WEM) and the Northern Territory Electricity Market (NTEM). Each has a separate regulatory arrangement.

The NEM and WEM are under the management of the Australian Energy Market Operator (AEMO), while the NTEM is managed by the Power and Water Corporation. These market operators use forecasting and monitoring tools to monitor electricity demand, allowing it to decide which power generators should be activated to generate electricity (AER 2021). Any person or organization who owns, controls or operates a generating system connected to a transmission or distribution network is considered a generator, allowing many private generators to participate in the market.

AEMO. in particular, prioritizes dispatching generators with the lowest bid prices and gradually includes more expensive ones until the electricity supply matches the demand. This enables the lowest net cost electricity to be dispatched first, minimizing overall electricity system costs to consumers. However, all generators are paid the same price, which is the highest dispatch bid price.

2.2.2. Direct government involvement

Both economy-wide and state/territory governments in Australia have adopted a relatively minimal approach to direct involvement in the energy market. The most active policy pursued involves establishing specific EES capacity targets.

EES targets

At the time of writing, there is no economy-wide target for EES capacity. However, many Australian states and territories have their own targets (Table 1). While targets do not directly drive investments as mandates and requirements can, they incentivize private investments by providing a clear regulatory signal to investors and businesses, indicating that there will be a demand for energy storage solutions in the future. In addition, targets can be accompanied by mechanisms, such as financial incentives. Targets are also accompanied by new policy instruments such as tenders or long-term service agreements (New South Wales's 2020 Electricity Infrastructure Roadmap), governments' commitment (Queensland's Energy and Jobs Plan) and government intervention in sectors which constituted the demand for energy such as the transport or agricultural sectors (Victoria's 2035 Emission Reduction Target).

Table 1: Government targets for EES by state or territory

State/Territory	Policy	Target capacity	Target year
Australian Capital Territory	Next Generation Energy Storage program	5,000 battery installations at Canberra homes and businesses	N/A (ongoing until the target is achieved)
New South Wales	2020 Electricity Infrastructure Roadmap	2GW of long-duration storage (e.g., PSH)	2030
Northern Territory	N/A		
Queensland	Queensland Energy and Jobs Plan	Borumba Dam Pumped Hydro (2GW/24 hours)	2032
South Australia	N/A		
Tasmania	N/A		
Victoria	Victorian renewable energy and storage targets	2.6GW	2030
		6.3GW	2035
Western Australia	N/A		

EES mandates/requirements

At the time of writing, there is no mandate or requirement from the economy-wide or state/territory governments regarding the adoption of EES technologies.

2.2.3. Government financial support

Instead of direct government mandates, many EES projects in Australia have benefited from government-provided financial supports. Such support may take the form of investments/co-investments or incentives such as subsidies, grants, tax credits or rebates. These schemes help reduce the large upfront costs associated with the installation and use of EES systems.

Different states and territories have different strategies in place. Queensland and Tasmania follow a state-centered approach – with most support from government investments (including investments from government-owned enterprises). The New South Wales Government mostly incentivizes private investments through various mechanisms. They include offering revenue underwriting through the Long-Term Energy Service Agreement (LTESA) framework, mapping the landscape for opportunities, providing guidance on the regulatory framework, and offering “recoverable grants” for eligible PSH developments (NSW Climate Energy Action n. d.).

Government investments/co-investments

The Australian Renewable Energy Agency (ARENA) – an independent agency of the Australian federal government which was established to support the global transition to net zero emissions – has provided direct funding for PSH and other EES technologies. For example, in December 2022, ARENA announced plans to fund AUD 176 million to eight new grid-forming battery projects across Australia under the Large-Scale Battery Storage Round (DCCEEW 2023). The Government of Australia also committed to invest up to AUD 1.38 billion in equity for Snowy 2.0 – a pumped-hydro battery megaproject in New South Wales (DCCEEW 2021).

In addition to economy-level investments, almost all state and territory governments have plans to invest in EES projects. Significant government fundings and support are often necessary to get PSH projects off the ground. For instance, the 250MW Kidston Pumped Storage Hydro Project relied on AUD 610 million of loan from the Northern Australia Infrastructure Facility, AUD 47 million of grant from ARENA, and AUD 150 million from the Queensland government (Ludlow 2023).

Financial incentives

The Government of Australia has also introduced several programs to incentivize the investment and installation of EES. At the economy-wide government level, Australia has rolled out the Small-scale Renewable Energy Scheme which provides individuals and businesses a financial incentive to install small generation units, solar water heaters and air source heat pumps. Although battery storage systems are not eligible to participate in the scheme, approved systems with an integrated battery may be eligible (Clean Energy Regulator 2023).

Across Australia’s six states and two territories, governments have established their own grant and subsidy programs targeted towards the development of EES.

Table 2 summarizes key financial support programs by state and territory governments to incentivize the development of EES technologies. Government incentives are provided in all states and territories, except for Queensland and Western Australia in which private rebate programs such as Tesla Powerwall solar battery rebates have been more dominant. Most states, except for Queensland and Western Australia, rely on household incentives for small-scale EES technologies such as batteries.

Table 2: Summary of State and Territory Government financial support programs to enable EES

State/territory	Program names	Detail
Australian Capital Territory	Next Generation Energy Storage Program	The provision of rebates and zero-interest loans to 5000 batteries in Canberra homes and businesses.
New South Wales	Pumped Hydro Recoverable Grants	Provides recoverable grants totaling AUD 50 million to project developers to assist with the cost of early stage, detailed feasibility studies for pumped hydro projects.
	Emerging Energy Program (AUD 55 million)	Provides an AUD 75 million grant funding to assist the development of innovative, large-scale electricity and storage projects in New South Wales (NSW Climate and Energy Action).
Northern Territory	Home and Business Battery Scheme	Provides an AUD 6,000 grant to homeowners, businesses, not-for-profit and community organizations for the purchase and installation of solar PV systems with an eligible battery and inverter, or for those who already have solar, for the purchase and installation of an eligible battery and inverter. An initial AUD 800,000 will be provided for the scheme which will fund grants for about 130 batteries (Northern Territory Government).
Queensland	N/A	
South Australia	South Australia Home Battery Scheme	Provides significant discounts totaling AUD 100 million for 40,000 households that purchase and install a solar battery system in their homes.
Tasmania	Energy Saver Loan Scheme	Provides no-interest loans to eligible applicants to fund the purchase price and installation of energy efficient products including solar panels and battery storage systems.
Victoria	Solar Homes Program	Provides interest-free solar battery loan will help eligible Victorian households to reduce the upfront cost of installing a battery on their home. These interest-free loans have replaced the Victorian battery rebate program since June 2023.
Western Australia	N/A	

2.2.4. Dispatch signals

Due to the decentralized structure of the wholesale markets, stored energy can be injected into the grid and be paid the settlement price as a generation asset. As discussed in Section 2.2.1, the three wholesale energy markets in Australia operate under merit order dispatch systems, wherein the ranking and dispatch of energy sources is based on ascending order of price through a bidding process between asset owners. Such system allows energy prices to vary throughout the day, based on supply and demand. This encourages investments in EES as they allow owners of the EES system to store energy during off-peak hours and use it during peak demand periods, generating incomes.

2.2.5. Investment signals for private EES investments

To effectively encourage private investors, investment signals must satisfy two criteria. First, investment signals must come early enough to consider the long development lead time of some EES technologies such as PSH which can take up to several years. Second, investment signals should last a sufficient time to recover the cost of investments and provide profitability. Due to the long development lead time, high up-front capital and operational costs, investors must be confident that once built, the EES system will be able to generate incomes for a long time.

In 2021, AEMO transitioned from a process where the wholesale electricity spot price was settled every 30 minutes, to one where the price is settled every 5 minutes. EES operators can take advantage of these price differences by engaging in arbitrage – charging when prices are low (e.g., middle of the day) and discharging when prices are high (AER 2022). This makes it financially attractive to build energy storage systems to capture those opportunities as EES technologies provides operators with the capability of storing electricity when prices are low, and discharge electricity when prices are high. As the prospect of income can incentivize investments in EES, allowing storage electricity to participate in the wholesale market is important.

Besides regulatory changes to how energy prices are settled, the Government of Australia has rolled out other initiatives to ensure efficient long-term investment signals. Most notable, the Capacity Investment Scheme (CIS) involves seeking competitive tender bids for renewable energy generation and storage projects that can fill expected reliability gaps.[2] Winning bidders in these auctions are offered long-term revenue agreements whereby the Government underwrites a project against an agreed revenue “floor” and “ceiling” (DCCEEW, n. d.). These contracts provide a clear revenue stream, offering confidence to investors in the financial viability of their energy generation and storage projects over an extended period.

Another investment signal in the Australian EES market are the LTESAs. LTESAs are a series of option contracts for a storage or generation project in New South Wales. They allow EES investors to hedge against investment risks, most importantly periods of low electricity prices and volatility. The enhanced protection provided by LTESA insurance could potentially broaden the range of counterparties that suppliers are open to trading within the wholesale contracts market (AEMO, n. d.).

2.2.6. Ancillary services payment

Besides revenues from discharging and selling stored energy in the wholesale market, EES systems can earn income from providing ancillary services. Ancillary services refer to functions that help grid operators maintain a reliable electricity

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[2] The CIS is the most significant investment in EES in Australia, aiming to underwrite 9GW of storage capacity by 2030. For more information about the CIS, refer to Capacity Investment Scheme - DCCEEW.

system, which are enabled by EES' ability to deliver a huge amount of power under a short period of time (Lee et. al, 2023). Annex A summarizes some key ancillary services provided by PSH.

In Australia, storage projects can participate in several ancillary markets by generating electricity by discharging energy or withdrawing energy by charging. The AEMO has actively worked towards reducing barriers to participation and building capability for inverter-based resources (including solar PV, wind turbines and BESS) in many of these ancillary service markets (AEMO 2024b). The three markets are Frequency Control Ancillary Services (FCAS), network support and control ancillary services, and system restart ancillary services (PwC 2019). Economic analyses from Meng (2021) shows that the primary revenue of Australia's EES projects comes from frequency controls services. For example, 70% of electricity sales revenue of the Hornsdale Power Reserve comes from the FCAS market.

2.2.7. Information and policy gaps

Australia serves as a valuable case study to examine effective approaches in EES market settings. There are still information and policy gaps that need to be acknowledged in shaping the market settings criteria.

Regulatory framework:

- A barrier to investment and development of EES projects is the long planning application and assessment process, as well as the cost of the process. The application process is especially lengthy for PSH projects due to their large sizes and potential environmental impacts (Nexa Advisory 2024). EES developers and other stakeholders would benefit from increased efficiency in terms of approval and planning.

Market mechanisms:

- Ancillary service markets such as congestion relief are absent. Although AEMC has flagged the introduction of new markets like Synthetic Inertia, these could potentially take several years to be introduced, and investors and banks do not currently consider them in financial modelling for projects (Smart Energy Council 2022). Ancillary services such as FCAS favours rapid response, short-duration assets, limiting profitability of EES technologies of greater than 2-3 hours duration (Nexa Advisory 2024).

Incentives and subsidies:

- While some states offered incentives and subsidies for energy storage, there was no consistent economy-wide approach. The lack of uniformity in incentives could potentially influence the location of PSH projects.
- There are currently few financial support mechanisms to incentivize investment in longer duration EES. For example, the CIS requires projects to have reached commercial operation date by 2030, thus favoring shorter lead time assets over technologies such as PSH (Clean Energy Council 2024).

2.3. People's Republic of China

Key findings – People's Republic of China
• China aims to achieve peak CO2 emissions by 2030 and carbon neutrality by 2060, with the energy sector responsible for 90% of China's GHG emissions. • Rapid economic growth led to a six-fold increase in electricity demand between 2000 and 2021, with non-renewable sources dominating the electricity sector. China is making significant progress in renewable energy generation, targeting 80% of electricity from non-fossil fuel sources by 2060. Due to grid constraints, EES has become crucial in accommodating China's growing renewable energy capacity. • China's energy market is transitioning to a more market-oriented structure, with the government promoting competition, attracting private investment and enhancing efficiency. However, government-led initiatives, including state and provincial mandates, are what is driving EES expansion. There is a lack of structural subsidy schemes, which could be used to alleviate the problem of high up-front capital costs of EES technologies that hinders private investments. • Despite the lack of structural subsidies, long-term investment in EES is being encouraged through offtake agreements, with a growing private investor role in China's EES sector. • Currently, only a few ancillary services provided by EES can participate in market competition, but policies are evolving.

China has outlined ambitious goals for decarbonization of the economy. In September 2020, President Xi Jinping announced a plan to achieve peak CO2 emissions by 2030 and carbon neutrality by 2060. Achieving carbon neutrality will be largely driven by the energy sector, which currently contributes almost 90% of China's GHG emission (IEA 2021).

High economic growth in the past few decades has led to massive expansion of the energy sector in China. Between 2000 and 2021, electricity demand has grown more than 6-fold (International Monetary Fund 2023). While the electricity sector is still dominated by non-renewable energy sources, especially coal and petroleum (EIA 2022), RE generation is becoming increasingly important. Since June 2023, non-fossil fuel energy sources have exceeded 50% of China's total installed electricity generation capacity (Reuters 2023).

Despite the expansion of RE, China's grid is unable to digest all electricity generation, leading to clean energy being wasted. According to Bloomberg's analysis, in 2022, around 10% of solar power in Qinghai and 12% of power generated by wind turbines in Inner Mongolia has been curtailed (Bloomberg 2022). As a result, EES has been identified as playing an increasingly important role in China's renewable sector (Wu 2022).

By the end of 2020, total installed energy storage project capacity in China reached 33.4 GW (CNESE 2023). By 2027, this is expected to rise to 97 GW. China currently holds the largest installed PSH capacity globally and intends to significantly expand it by 2030. In 2021, there were 136 approved energy storage projects, comprising 131 electrochemical and 5 PSH projects, on top of existing EES capacity (Bian 2023).

2.3.1. Understanding the Chinese energy market

China's energy market has undergone significant reforms in recent years, transitioning from a largely vertically integrated structure wherein the government of China controlled most of the assets related to the generation, transmission and distribution of electricity, to a more market-oriented system (Ho et. al. 2017). While the economy's energy sector is still dominated by state-owned enterprises, efforts are being made to introduce competition through private participation.

In 2019, 30% of the total generating capacity in China was dispatched through market-based electricity trading mechanisms (Supponen et. al. 2020). More recently, China has established an independent regulatory agency, a competitive electricity market and relatively independent power trading exchange centers. These reforms aim to promote competition, attract private investment, and enhance efficiency in the energy sector.

The State Grid Corporation of China (SGCC) and China Southern Power Grid (CSPG) are the two main grid operators responsible for electricity transmission. The role of state-owned enterprises (SOEs) is pivotal as the introduction of new technologies such as EES often comes with increased risks from an investors' points of view, and SOEs are not as constrained by pure economic considerations, making them important players in China's market settings strategy.

China is implementing changes in the dispatch system by introducing more market-oriented features (Ho et. al., 2017). Traditionally, dispatch prices have been entirely determined by the government rather than being market driven (Liu et. al. 2022). In 2015, the State Council of China launched *Several Opinions on Further Deepening the Reform of the Power System* which initiated a substantial reform to gradually liberalize the wholesale and electricity sector. The reform established the mid- to long term and the spot market (day-ahead and real time) wherein the price is set by market factors. Approximately half of the electricity consumed in the economy and about four-fifths of the traded volume is covered by medium to long-term contracts, with most lasting for one month to one year (You and Xuan, 2023). Since 2017, China has rolled out electricity spot trading pilots in 14 provinces.[3] Between 2017 and 2022, the proportion of market-traded electricity increased from 25.9% to 60.8% (Yongping et. al. 2023).

Under the medium to long term market, wholesale energy prices are decided via negotiation or auction between generators or suppliers and large consumers (IMF 2023). Participants sign physical energy contracts that determine a price and total amount of energy supplied (Guo et. al. 2020). Spot markets are either day-ahead or real time and the pricing mechanism is different in each province. Despite these reforms, there is currently no effective market mechanism to guarantee the income of RE generation units after participating in China's spot markets (Wang et. al. 2022).

[3] Guangdong, west Inner Mongolia, Zhejiang, Shanxi, Shandong, Fujian, Sichuan and Gansu established pilot markets in 2017, and Liaoning, Shanghai, Jiangsu, Anhui, Henan and Hubei followed in 2021.

Administrative mechanisms still play a significant role in dispatch and pricing through the planned fair dispatch mechanism (IMF 2023).

In 2022, the National Development and Reform Commission publishes guidelines to establish a unified domestic energy market. Article 14 of China's REL 2005/2009 requires that renewable energy generators are to be given mandatory access to the grid and that electricity generated from RE is to be fully purchased by the grid enterprises.

2.3.2. Direct government involvement

With a partially liberalized electricity market with the majority of electricity infrastructure owned by the state, the expansion of the EES market in China is highly motivated by government-led initiatives. Between 2010 and 2020, there has been a significant increase in the number of EES-related policies (Fan et. al. 2021).

EES targets

On 21 March 2022, the Implementation Plan for the Development of New Energy Storage Technologies during the 14th Five-Year Plan Period (the 14th FYP for Energy Storage) was jointly issued by the National Development and Reform Commission and the National Energy Administration. This Plan advocated for a broader collaboration involving governmental and private entities to nurture the energy storage sector. Following the Plan, more than 20 provinces have announced their goals to install EES systems which will have a combined capacity of over 40 GW in addition to the existing installed capacity (Wu 2022). Table 3 details the targets set by some provinces. China is targeting 62GW of installed PSH by 2025 and 120 GW by 2030 (Belt and Road Energy Cooperation 2021).

Table 3: EES capacity targets in some provinces

Province	Policy	EES capacity target by 2025 (GW)
Shandong	14th Five-Year Plan for Energy Development of Shandong Province	4.5
Gansu	14th Five-Year Plan for Energy Development of Gansu Province	6
Tianjin	14th Five-Year Plan for Energy Development of Tianjin Province	0.5
Henan	14th Five-Year Plan for Modern Energy System and Carbon Neutral of Henan Province	2.2
Qinghai	14th Five-Year Plan for Energy Development of Qinghai Province	6
Inner Mongolia	14th Five-Year Plan for Electricity	5
Anhui	Novel Energy Storage Development Plan of Anhui Province	3

Province	Policy	EES capacity target by 2025 (GW)
Hebei	14th Five-Year Plan for Novel Energy Storage Development of Hebei Province	4
Guangdong	14th Five-Year Plan for Energy Development of Guangdong Province	2
Zhejiang	14th Five-Year Plan for Energy Development of Zhejiang Province	1
Hubei	14th Five-Year Plan for Energy Development of Hubei Province	2

EES mandates

In China, EES mandates are an important policy tool. In 2021, the National Energy Administration ordered grid companies to include a certain proportion of energy storage capacity in a new solar and wind generation project (Shaw 2021). As of May 2022, 23 provinces in China introduced mandatory requirements of construction of energy storage capacity to match at least 10% of a renewable project's installed capacity (Bian 2023). In practice, power generation firms in China have expressed that government mandates of pairing renewable projects with EES facilities drive up project costs of land acquisition and building out the facilities themselves, lowering projects' returns (Ng 2022). According to a major state-own utility, for an energy storage facility to have a 10% installed capacity of a renewable project and a storage duration of two hours, it will result in a 1 percentage point reduction in the project's overall internal rate of return (Lu and Mo 2023). If mandates are paired with financial support that tackles the issue of EES systems' high up-front capital expenses, they could potentially enhance their effectiveness in promoting investments in EES.

2.3.3. Government financial support

Government investment/co-investment

Government investments are crucial in advancing EES technologies by improving their performance and reducing costs for installers. In China, storage assets are considered grid assets which are largely developed and managed by state-owned grid companies – SGCC and CSPG (Genex Power 2022). Most investments and fundings in PSH stations come from the states through the two state-owned power grid operators. By 2022, 27 projects are scheduled to be commissioned over the period 2022-2030, of which 19 are being built by subsidiaries of the SGCC and CSPG (Genex Power 2022). For example, in 2019, the SGCC invested CNY38.7 billion (USD5.66 billion) to build five PSH plants across the economy which are expected to be launched in 2026.

Financial incentives

According to the 14th FYP energy storage implementation plan, China aims to leverage public fundings to attract private capital in carbon-neutral technologies, including EES. This signals a move from the traditionally state-dominated business model in which technologies are driven by investments from governments or SOEs to one in which the government provides support and guidance to foster private investment.

According to the current effective Catalogue of Industries for Encouraging Foreign Investment (2020 Version) and the proposed 2022 draft, foreign investors face minimal restrictions to access the EES sector. Foreign investment in research and development, and deployment of large-scale energy storage technologies are strongly encouraged (National Development and Reform Commission 2022).

There is currently no economy-wide subsidy or incentive program for EES. Subsidies and tax incentives are *ad hoc* measures and tend to be adopted at provincial level. For instance, in January 2023, Changzhou introduced a subsidy program under which investors in new energy storage stations with an installed capacity of 1 MW or more would receive a subsidy of up to RMB 0.3 per kilowatt-hour (kWh) (CNESA 2023).

2.3.4. Dispatch signals

Due to the relatively recent plans of PSH development, PSH projects in China follow different revenue models.

Generation-based feed-in-tariff

Under the generation-based tariff system, the State Department establishes a tariff based on the electricity generation for each PSH storage project. This tariff aims to cover the project's construction and operational expenses. Most PSH plants built before 2004 adopted the generation-based tariff regime (Zhanga et. al. 2015). For example, the Shisanling Plant receives a feed-in-tariff of RMB 0.80 for every kWh of energy generated. In contrast to the Australian model, China's generation-based feed-in-tariff model precludes the use of arbitrage and ancillary service provision. Generation-based tariffs mainly facilitate EES development by incentivizing the EES owner to generate more energy. This model could be augmented by adding markets to compensate for critical ancillary services like frequency response, voltage support and operating reserves.

Two-part tariff

The two-part tariff, also referred to as dual-rate pricing system, is a blend of a fixed yearly **capacity-based payment** and a **generation-based payment**, both of which receive approval from the National Development and Reform Commission. The capacity payment covers the value of ancillary services provided such as system reserves, frequency and voltage regulation and black start capabilities. On the other hand, the generation tariff is structured to offset variable operational costs like pumping and generation losses (CSHE 2021). This approach ensures a reasonable return rate and incentivize EES investments with the revenue prospects from ancillary service compensations. Still, projects that follow this revenue model do not benefit from energy arbitrage. This pricing model is implemented at the Zhejiang Tianhuangping Pumped Storage Power Station.

Spot market mechanism

Aligning with electric power system reforms and the rise of spot markets, the National Development and Reform Commission issued guidelines for setting PSH units' electricity prices. It mandates that in active spot markets, the pumped storage electricity price and feed-in price should follow spot market prices and rules (Wang et. al. 2022).

The revenue of PSH units can consist of two components: the **capacity tariff** and the **electricity tariff**. The electricity tariffs follow the electricity spot market prices (Wang et. al. 2022, p. 2). The real time market has a transaction cycle of 5 minutes, allowing developers to take advantage of price volatility (He et. al. 2021). This model has the potential to encourage private investments by providing the income prospects from both energy arbitrage, through the electricity tariff, and ancillary service, through the electricity tariff.

2.3.5. Investment signals for private EES investment

The Chinese Government encourages long term investment by promoting offtake agreements. For example, the salt cavern compressed air energy storage project in Changzhou, Jiangsu province, has a 20-year PPA with the State Grid Corporation of China. Similarly, the BESS project in Dalian, Liaoning province, operates under a 15-year PPA with the Northeast Power Grid Company

The capacity-based Lease Arrangements provide investment signals for several PSH projects on China. Under the arrangements, an annual fee is established which the grid company pays to rent the facility from the project owners. This fee includes all project expenses (except for the electricity cost during pumping operations) and taxes, while also yielding a roughly 5% return on investment (China Society for Hydropower Engineering 2021).

2.3.6. Ancillary services

In China, few ancillary services provided by PSH can participate in market competition. Taking the Northeast Power Market as an example, only two ancillary services – peak shaving and black-start – can participate in the market (Zhang et. al. 2018). Under the two-part tariff-scheme, the capacity fee remunerates only services of power system reserves, regulation and black-start (Nibbi et. al. 2022). The pricing mechanism of many ancillary services is not market-based, leading to many remunerated services not being fairly remunerated. For the excess pumping power and black-start service provided by PSH, the administrative pricing method is used to give a small amount of compensation, which does not reflect the true market value of these services (Zhang et. al. 2018). Up until recently, most battery storage projects were barred from participating in ancillary services markets since they were not classified as power generators, discouraging investments in these projects (Jenkins and Cao 2022). However, there have been positive policy signals from the Central Government. In December 2021, China's National Energy Administration published a draft update to the Measures for Administration of Ancillary Services which added more ancillary products and expanded eligible market participants. The new rules name non-generating assets (e.g., storage electricity) as eligible market participants, removing the market-entry barrier and enabling new revenue streams for them. However, the impact of this change remains to be seen.

2.3.7. Information and policy gaps

While there have been market-based reforms, administrative rules still play an important role in the EES market. This worked at the early stages as being new, EES technologies were still considered risky and SOEs were more able to take on risks. However, with China's far-reaching EES targets, SOEs alone are unable to close the investment gaps, especially as the EES sector scales up. Many challenges currently facing China revolve around a lack of incentives for private investments.

Regulatory frameworks:

- There is a lack of unified economy-wide electricity market and rules. In recent years, many energy storage policies have been introduced at provincial and central levels. However, lack of clarity and coherence could undermine investor understanding and confidence. In response, there have been plans to establish a unified economy-wide electricity market under the 14 FYP.
- In China's electricity industry, there is an absence of a formal mechanism that allows market participants to seek bottom-up clarification on EES regulations (Zhang and Yang 2019).
- There are issues of policy uncertainty. Marketization is still at a transitional stage, which means future regulatory changes could put projects with a long investment payback period at risk, thus discouraging investors (CNESA 2019).

Market mechanisms:

- Mechanisms underpinning the market still depend largely on administrative rules. For example, China's electricity dispatch system is determined by the annual power generation plan that is designed by provincial governments. During a power shortage with limited electricity supplies, the government often prioritizes rationing measures over market-based instruments, which may hamper the dispatch signals to storage projects and affect projects that rely on arbitrage. Fan et. al. (2021) argues that the key of promoting the commercialization of energy storage – the electricity spot market under which storage projects benefit from price arbitrage – has not been fully established (Fan et. al. 2021).
- Some ancillary services are not remunerated or considered fairly remunerated.

Incentives and subsidies:

- Much of the development in EES projects has been accomplished by direct government investments as well as government mandates. This may not address the root cause of lack of investment which is the high up-front capital cost. Subsidies are implemented in an *ad hoc* manner and there is currently limited coherent economy-wide subsidy/incentive scheme for EES.

2.4. United States

Key findings – United States
• The United States' EES market grew steadily between 1960 and 1990, with 43 PSH facilities built in the period. Capacity increases between 2010 and 2019 resulted from upgrades to existing PSH plants. • The United States' electricity market is diverse, with various market structures and regulatory frameworks across states. • Government involvement in the domestic EES includes both mandates and targets for energy storage adoption. Certain states have required utility resource plans to include EES technologies, while others have set procurement mandates, primarily for short-duration BESS. Government investment in EES market settings has scaled back, with a focus on refurbishing and upgrading existing hydropower and PSH facilities. Financial incentives have been introduced to stimulate investment in standalone energy storage facilities and PSH projects. • EES is integrated into ancillary services markets, contributing to annual revenue, especially in the case of PSH. • However, there are policy gaps in the regulatory framework, with discrepancies between state-level and wholesale market rules. There is uncertainty about how energy storage assets are classified.

The United States electrical energy storage market has been on an upward trajectory, witnessing remarkable growth and transformation in recent years. Across all EES technologies, PSH plays a significant role by providing about 94% of grid-scale energy storage capacity (International Forum on Pumped Storage Hydropower 2021). Similarly, according to the 2021 Hydropower Market Report, PSH presently constitutes 93% of the total utility-scale energy storage infrastructure within the United States. The economy is presently home to 43 PSH facilities, with the capacity to potentially expand this number, effectively doubling the current PSH capacity (US Department of Energy 2021). All these facilities were built by the United States' Government and investor-owned utilities between 1960 and 1990 but since then, no new PSH systems have been built. The 1400 MW increase in PSH capacity between 2010 and 2019 was driven by the upgrades to existing PSH plants (US Department of Energy 2021). Figure 3 shows the increase in the number active PSH projects.

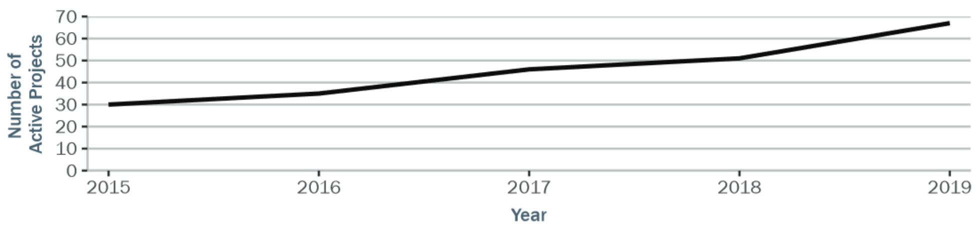


Figure 3: US PSH project development activity (2015-2019) (Source: FERC eLibrary)

2.4.1. Understanding the United States energy market

The United States electricity market is highly diverse, with a complex mix of market structures and regulatory frameworks across different states and regions. In general, the United States electricity market can be classified into two categories: wholesale and retail market.

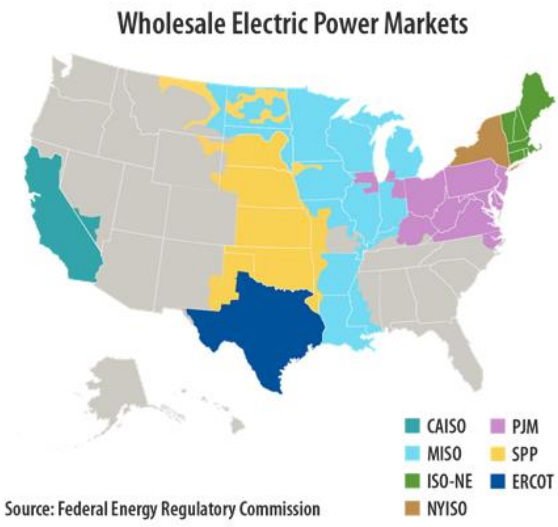


Figure 4: Power market distribution in the United States

Many states in the United States operate wholesale electricity markets (identified in Figure 4), regulated by the Energy Regulatory Commission (FERC). Some of these wholesale markets follow traditional regulation, where vertically integrated utilities handle the entire process of electricity generation, transmission, and distribution. In contrast, other wholesale markets are restructured as competitive markets, operated by independent system operators or regional transmission organizations. In contrast, other wholesale markets are restructured as competitive markets, operated by independent system operators (ISOs) or regional transmission organizations (RTOs). These independent entities, similar to Australia's AEMO for the NEM, ensure smooth market operations. In these competitive markets, Independent Power Producers (IPPs) and non-utility participants can engage in energy trading. Table 4 provides details on these markets, including the ISO or RTO overseeing each market and the states they cover.

Table 4: States and applicable ISO/ RTO that oversees the market

States	ISO/RTO name
California	California Independent System Operator (CAISO)
Texas	Electric Reliability Council of Texas (ERCOT)
Kansas, Oklahoma, New Mexico, Texas, Arkansas, Louisiana, Missouri, South Dakota, North Dakota, Montana, Minnesota, Iowa, Wyoming, and Nebraska	Southwest Power Pool (SPP)
Arkansas, Illinois, Indiana, Iowa, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Montana, North Dakota, South Dakota,	Midcontinent Independent System Operator (MISO)

States	ISO/RTO name
Texas, and Wisconsin	
Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia	PJM Interconnection
New York	New York Independent System Operator (NYISO)
Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire and Maine	Independent System Operator of New England (ISO-NE)

Additionally, some states use a retail electricity market model, allowing electricity to be sold directly to consumers. Retail markets can be traditionally regulated — where consumers have no choice in their power generator — or competitive, allowing consumers to select from various retail electricity providers (EPA 2023).

2.4.2. Direct government involvement

Direct government involvement in the United States EES market settings is characterized by a combination of mandates and targets.

EES targets

Around 10 states have adopted procurement targets for EES (Lazaroff and Curran 2023). Efforts to achieve these targets vary across states. For instance, New York and Massachusetts have been using various mechanisms to improve deployment, while New Jersey's goal remains aspirational (Colthorpe 2020).

EES mandates

As of 2022, five states have opted to set a procurement mandate for EES. However, most mandates are geared toward short-duration battery storage rather than PSH (US Department of Energy 2023, p. 123). Table 5 details procurement mandates at the state level as of mid-2022.

Table 5: State-level procurement mandates (as of mid-2022) (Source: McNamara et. al. 2023)

State	Mandate	Mandate year
California	1825 MW	2020
New Jersey	6000 MW	2030
New York	6000 MW	2030
Oregon	Utilities under the jurisdiction of the Oregon Public Utilities Commission to have a minimum of 5 MWh of EES.	2020
Virginia	3100 MW	2035

2.4.3. Government financial support

Government investment/co-investment

Although government investment plays a major role in EES development, the magnitude of investment has scaled back over time. The 2020-2022 annual average investment in refurbishing and upgrading US hydropower and PSH fleets was USD363 million, less than half the annual average for 2010-2019. This is reflective of the US Department of Energy expectation that incentive payments can stimulate investment in non-federal fleet (US Department of Energy 2023).

Rather than funding for building new plants, government investments in PSH specifically target rehabilitation and upgrade of existing facilities. Between 2010 and 2021, USD 7.8 billion was invested in refurbishments and upgrades of the US hydropower and PSH fleet (US Department of Energy 2021). Figure 5 shows the annual expenditures between 2010 and 2019.

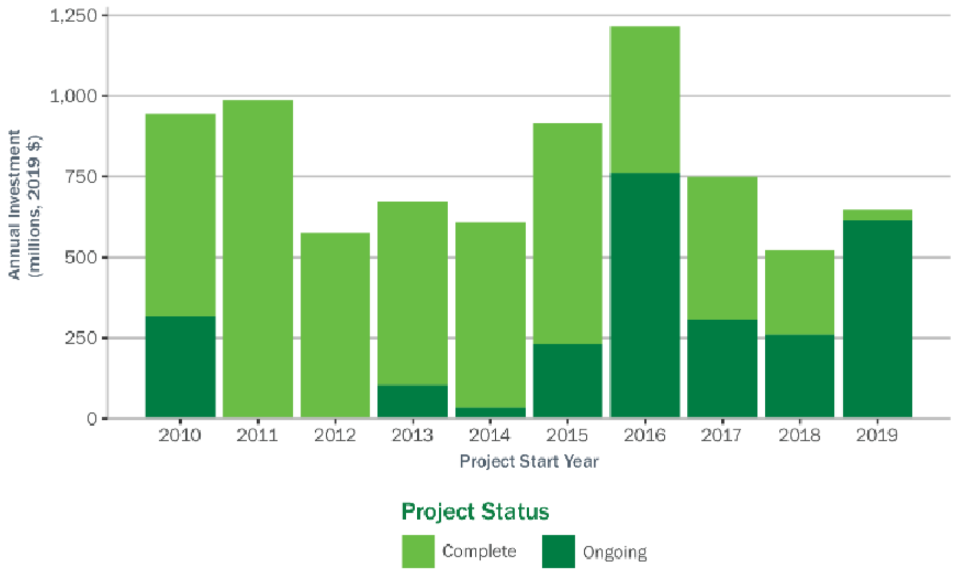


Figure 5: Expenditures on rehabilitations and upgrades of the existing hydropower and PSH fleet (Source: US Department of Energy 2023)

Financial incentives

The Inflation Reduction Act (IRA) stands out across existing financial incentives for EES projects for its scale and public attention. The IRA is an economy-wide Act which came into effect on 1 January 2023 and includes an investment tax credit for investment in standalone energy storage facilities of more than 5kWh (Colthorpe 2023). Historically, only storage projects that are paired directly with solar PV were eligible for investment tax credits. According to BloombergNEF's head of energy storage, companies have been scaling up operations since the IRA was announced to capture the upside brought about by the incentive scheme (BloombergNEF 2022).

In terms of PSH, the Bipartisan Infrastructure Law allows owners or operators of existing hydroelectric facilities, including PSH, to apply for funding to make capital improvements that can improve their efficiency by at least 3% (US Department of

Energy, n.d.). This incentive may, however, have contributed to the decline in activity in 2021-2022 because plant owners were waiting for full guidance on how these incentives would be implemented before committing to any new capital investments (US Department of Energy 2023). The IRA also provides for tax credits for PSH if certain conditions are satisfied. In particular, Section 48 of the IRA states that eligible hydropower and PSH placed in service during 2022-2024 are credited 30% of eligible investment cost and an additional 10 percentage point of credit if the project meets domestic content requirements or is located in an "energy community."

In addition to the federal IRA, a number of states have rolled out different incentive programs for EES installation and investments, summarized in Table 6.

Table 6: State incentive programs for EES installation and investments

State	Program name	Details
California	California's Self-Generation Incentive Program (SGIP)	Provides a dollar per kilowatt (USD/kW) rebate for installed energy storage systems. The rebate rate steps down as more homes and businesses add storage. In 2020, the state updated SGIP to provide more funding and higher levels of incentives for customers in high fire threat districts, and for low-income customers, to help provide emergency backup power to those who need it most.
Connecticut	2022 Energy Storage Solutions program	Provides upfront incentives and performance payments for behind-the-meter energy storage. Incentives range up to USD7,500 for residential customers, starting at USD200 per kWh. Commercial and industrial customers may receive incentives of up to 50 percent of project costs for storage installations. Performance payments are based on storage discharge in response to a utility signal, which allows distributed systems to be aggregated and dispatched to lower peak electricity demand. Additional incentives are available to low-income and underserved communities.
Maryland	Tax credit	Covered 30 percent of the cost of a storage system, up to USD5,000 for residential batteries and up to USD150,000 for commercial batteries. However, this program was only authorized through the 2022 tax year; Maryland Energy Administration is currently in the process of launching a replacement energy storage incentive program, which will be grant-based.
Massachusetts	Commonwealth's solar-focused SMART incentive program.	For residents installing storage with a solar PV system, the per-kilowatt-hour solar production incentive increases as a result of purchasing storage as well. Massachusetts has also incorporated battery storage into its energy efficiency plan through the Connected Solutions program, and customers can now enroll their behind-the-meter batteries into the program through a utility contract, making them eligible to receive performance payments. And, Massachusetts has developed the economy's only Clean Peak Energy Standard, which requires utilities to procure increasing amounts of clean peaking power from renewables and energy storage.

2.4.4. Dispatch signals

Even without government subsidies and tax credits, EES is already taking cues from the high arbitrage potential locations with growing renewable generation. According to the US Energy Information Administration, arbitrage stood among the top three applications based on energy capacity across all electricity markets in the United States in 2019 (EIA 2021). In 2021, 59% of the 4.6 GW of utility-scale US battery capacity was devoted to price arbitrage, a substantial increase from the 17% observed in 2019 (EIA 2022). In the CAISO market, over 80% of the battery capacity added in 2021 were employed for price arbitrage purposes.

In the CAISO market, storage energy participates under the non-generator resource (NGR) model. NGRs are resources that operate as either generation or load (demand) and bid into the market using a single supply curve with prices for negative capacity (charging) and positive capacity (discharging). For their day-to-day operations, NGRs have the option to use several biddable parameters to manage their state-of-charge. They can submit upper and lower charge limits for each trading day which represent the highest and lowest stored energy values (in MWh) that must be maintained in the resource. For greater control in how their state-of-charge changes throughout the day, resources may use the end-of-hour state-of-charge parameter. NGRs can submit an initial state-of-charge value to indicate the available energy on the first participation interval of the trading day in the day-ahead market. The market software will default this value to the ending state-of-charge from the previous day if market participants do not submit an initial state-of-charge, or zero MWh if neither are available.

2.4.5. Investment signals for private EES investment

By the end of 2020, 159 GW of solar capacity in the United States (around 34%) operated as hybrids, most commonly combining PV with battery storage. Over 18 GW of PV-storage projects have secured offtake agreements, such as a PPA. The levelized PPA price from those projects has declined over time (Wiser et. al. 2021). As shown in Figure 6, projects with higher battery storage to PV capacity tend to receive higher levelized storage adders. This acts as an incentive to large-scale storage systems. Figure 6 shows trends towards providing PPA to projects with more storage capacity.

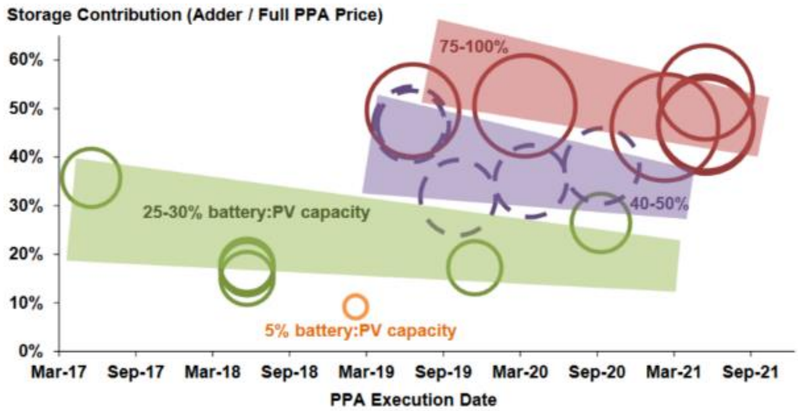


Figure 6: Storage Contribution (Adder/Full PPA Price) by the Project's PPA Execution Date

2.4.6. Ancillary services

In October 2011, the US Department of Energy released Pay for Performance which incorporates energy storage technology into the range of ancillary service and adjusts its market price signals. This makes the competition fairer between energy storage and traditional generation. In addition, local governments have also made corresponding policies.

In terms of PSH, data between 2014-2018 shows that for some PSH projects, a combination of capacity payments and ancillary service revenues accounted for more than half of annual revenue (US Department of Energy 2021). Figure 7 shows the revenue composition differentiating of different ancillary services. The percentage of total revenue from provision of ancillary services (frequency regulation, voltage control, spinning or supplemental reserve, black start) ranged between 0.1% and 26% across the plants and periods considered.

Figure 7: Annual revenue streams for selected PSH plants (ancillary services) (Source: US Department of Energy 2021)

2.4.7. Information and policy gaps

The United States provides a useful case study for examining diverse approaches in EES market settings. There are key information and policy considerations to address as regulatory frameworks continue to evolve across federal, wholesale, and state levels.

Regulatory framework:

- The United States does not have a federal standard or mandate for energy storage deployment. There are current disconnections between wholesale market rules (set by ISOs and RSOs and approved by the FERC) and rules developed at the state/retail level (McNamara et. al. 2023). This shows the difficulty investors may face when there are conflicting obligations when wholesale market rules are outside the state's jurisdiction.

- It is not always clear to investors what type of asset EES falls under. Market rules generally prohibit transmission assets from participating in wholesale energy and ancillary service markets to maintain the independence of grid operators and avoid the potential for market manipulation, whether real or perceived. The policy also prohibits sales of ancillary services by a third-party supplier to a public utility that is purchasing ancillary services to satisfy its own obligations to customers under its open access transmission tariff. This restriction removes the income prospects from EES-supported ancillary services. This clear distinction between transmission and generation assets is problematic for energy storage, because pumped storage or other energy storage projects have components of both transmission and generation. The possibility of establishing bulk energy storage as a new asset class is being discussed with the FERC and other regulatory bodies and will evolve along with market needs and preferences (National Hydropower Association 2017).
- Barriers that exist primarily within state policies include an absence of policies for EES in general or long-duration EES specifically (only about 15 US states have substantive energy storage policies, and only a few have addressed long-duration EES specifically).

2.5. Implications and lessons learned from case studies

Despite their differing market structures, Australia; China; United States demonstrate common effective practices for developing domestic EES markets. These case studies offer valuable insights into regulatory frameworks, market mechanisms, and incentives that support investment in EES technologies.

Government involvement

- **Transition to private investment:** Over time, government involvement in EES markets can shift from direct investment to fostering private investment. Private investment is important to reduce government budget pressure. However, given that the construction costs of many EES technologies are still relatively high in many member economies, governments should still engage with the market to attract private investors and capital. Governments can play a guiding role by creating laws that encourage private investment (e.g., allowing and incentivizing foreign investment) and by providing financial incentives that make private-sector participation attractive.
- **Regulatory instruments:** Regulatory instruments may include economy-wide and sub economy-wide targets for EES capacity, mandates and financial incentives for private investment and ownership of EES technologies. These tools create a stable and predictable market environment and provide signals to the private sector on future market demand, encouraging long-term investments.

- **Evolving EES technologies:** Governments should recognize that different EES technologies serve distinct roles (e.g., short-term versus long-term storage). Markets and policies should evolve to accommodate various technologies (e.g., BESS versus PSH) depending on the grid's needs for flexibility and reliability.
- **Transparency and clarity:** Regulatory frameworks governing EES markets must be clear and transparent for all stakeholders, including private investors and utilities. Transparent rules increase investor confidence and reduce the risks associated with regulatory uncertainty.
- **Consistency and communications:** Rules within different jurisdictions should be consistent, especially in economies with decentralized or multi-level governance systems in the energy market (e.g., Australia). Where inconsistencies exist, they must be clearly communicated to stakeholders. There should be mechanisms for stakeholders such as the private sector to seek clarification on complex rules or regulations.
- **Combination of mandates/targets and support:** Regulatory mandates for EES capacity are more effective when coupled with financial incentives. Combining mandates with financial support mechanisms helps address the root challenge of high upfront capital costs of developing EES systems, which is a key barrier to investment. Governments may provide financial assistance through direct government investments or co-investments in the case of government-owned EES projects, or financial incentive/subsidy schemes to encourage private investments in privately owned projects.
- **Holistic market reforms**: In economies transitioning from government-led to market-oriented energy sectors (e.g., China), comprehensive reforms are needed to ensure that market-based mechanisms (e.g., spot markets and competitive bidding) work in tandem with regulatory and administrative policies. Reforming pricing mechanisms, grid access and market participation rules can increase private sector involvement.
- **Support for emerging technologies**: Governments should create opportunities for the adoption of emerging EES technologies through research and development funding, pilot programs, or early-stage market support, ensuring that technologies are aligned with grid needs and energy security goals.

Market mechanisms

- **Dispatch signals:** Efficient energy dispatch systems are essential for the success of EES. The merit-order dispatch model, where energy sources are ranked by price, should settle prices frequently to capture price volatility. Australia's example of 5-minute intervals for dispatch pricing creates more granular opportunities for revenue, enhancing the financial attractiveness of EES investments.
- **Opportunities for energy arbitrage:** Depending on the market structure, energy arbitrage might be beneficial in attracting private investment as it

allows owners to charge and store energy when prices are low and discharge and sell energy when prices are high, thus making a profit.

- **Long-term investment signals:** Effective investment signals, such as power purchase agreements, capacity payments and offtake agreements, provide investors with the long-term certainty needed to commit to building new EES capacity. These signals should be provided well in advance (at least 5 years ahead of anticipated demand) and should last for a significant portion of the asset's economic life (e.g., 20 years) to build investor confidence.
- **Competitive bidding processes:** Governments can create transparent and competitive bidding processes for renewable energy and storage projects. These processes encourage efficiency and ensure that the best projects, both in terms of cost and performance, receive funding or approval.
- **Ancillary service markets:** EES can generate additional revenue by providing ancillary services, such as frequency regulation, voltage support and black-start capabilities, that are essential for grid stability. Governments should ensure that these services are fairly compensated, creating new channels of revenue that enhance investment signals.

3. Criteria of good market settings to promote EES investment

EES play a crucial role in the evolving energy landscape, offering essential benefits such as enhanced grid stability and better integration of renewable energy sources. However, the success of EES deployment depends largely on the market conditions in which it operates. Drawing from the case studies of Australia; China; United States, the three main criteria are proposed for assessing market settings in APEC member economies.

1. Regulatory frameworks

Flexible policy toolkit: Various policy instruments such as economy-wide or sub economy-wide targets or mandates could be used to provide direction and drive investments. For example, the member economy may implement mandates for integrating EES with renewable energy projects. While policies such as targets will not directly drive investments, they send a strong signal to businesses and private investors that the demand for EES will grow, making it easier for the private sector to plan.

Clarity, consistency and transparency: Regulations governing EES markets must be clear, consistent and transparent. This ensures that private investors and stakeholders can confidently participate in EES development without facing regulatory uncertainty. However, since EES technologies are still quite new in many member economies, changes and inconsistencies may be inevitable. In this case, changes must still be clear, and they must be streamlined to relevant stakeholders.

Stakeholder engagement: There should be mechanisms in place for stakeholder consultations, allowing input on regulatory changes to accommodate evolving technologies and market needs.

Diverse EES technologies: Regulatory frameworks and market policies should accommodate a range of EES technologies (e.g., BESS, PSH) that can provide flexibility and reliability to the grid.

Support for emerging EES technologies: Governments should create opportunities for the adoption of emerging EES technologies through research and development funding, pilot programs or early-stage market support.

Integration of EES technologies in system planning: By transparently providing signals about emerging areas of demand and potential grid congestion, system planners can guide EES deployment to areas where it can deliver the most value, both in terms of grid impact and economic returns for investors.

2. Financial support

Government investment/co-investments: Direct government investment or co-investment in large-scale EES projects, especially in early-stage development when the costs and risks are too high for private investors to step in, is crucial. This financial support can help reduce risks for private investors and accelerate the deployment of key projects like PSH, while ensuring alignment with economy-wide energy goals.

Financial incentives: To address high upfront costs of EES projects, governments should offer financial incentives such as subsidies, grants, or tax credits. These incentives can encourage private sector participation and foreign investment.

3. Market mechanisms

Investment signals: Investment signals tell investors when to invest. They must satisfy two criteria: (1) must come early enough and (2) must last for a long time. Effective market signals are essential for attracting investment in EES. Long-term PPAs, capacity payments, and offtake agreements should provide certainty and stability for investors.

Energy arbitrage: Where appropriate, markets may enable EES operators to take advantage of energy arbitrage, allowing them to store energy during low-price periods and sell during high-price periods, thereby creating a profitable business model.

Ancillary service markets: EES systems should be allowed to participate in ancillary service markets (e.g., frequency regulation, voltage support). Adequate and fair compensation for these services creates additional revenue streams, boosting investor confidence.

4. Assessment of current EES market settings in Malaysia; Papua New Guinea; Thailand

A comprehensive assessment of EES market settings in Malaysia; Papua New Guinea; Thailand is necessary for several reasons.

First, Malaysia; Papua New Guinea; Thailand were among the six member economies of the APEC that had previously volunteered for the PRLCE. These economies have made significant commitments to the transition towards low-carbon energy policies, especially by utilizing RE sources. The adoption of EES technologies in each of these economies must be a priority.

Second, the energy landscapes in these economies are currently undergoing substantial changes. Rapid economic growth, urbanization and an escalating demand for electricity are spurring the necessity for more efficient and adaptable energy infrastructure. In an era with rapidly growing VRE generation capacity, EES technologies possess the capability to increase grid stability, avoid curtailment of renewably generated electricity, and ease pressure on generating assets during peak demand periods in each individual economy.

Third, the adoption of EES technologies in Malaysia; Papua New Guinea; Thailand remains largely in its early stages. This project offers a valuable opportunity to build and streamline awareness regarding various facets of EES.

This section presents an overview of the energy markets and current EES adoption plans in Malaysia; Papua New Guinea; Thailand, providing a detailed assessment of their EES market settings based on the criteria outlined in Section 3.

4.1. Malaysia

Key findings – Malaysia

- The Malaysian energy market is regulated by the Ministry of Energy and Natural Resources, with various agencies managing electricity generation, transmission, and distribution. While the energy generation sector includes both public suppliers and private IPPs, the transmission and distribution networks are state-owned and monopolized by Tenaga Nasional Berhad (TNB).
- EES in Malaysia offer several benefits. They help reduce energy curtailment by storing excess energy from sources like solar power. EES assists in lowering electricity costs, especially during peak demand periods, by reducing the need for expensive peak power plants.
- EES in Malaysia is still in its early stages, with most installed capacity in BESS and small-scale/off-grid systems. With the National Energy Transition Roadmap, Malaysia aims for utility-scale EES to support renewable energy integration, targeting full grid-connected BESS integration by 2030.
- Malaysia's EES market faces high investment costs, with limited private sector involvement. Financial incentives and international partnerships are supporting development, though regulatory frameworks for large-scale adoption and ancillary service markets are still evolving. Programs like NOVA-VPP facilitate energy arbitrage, but long-term investment signals remain uncertain.

4.1.1. Economy background

Malaysia is the third largest economy in the Association of Southeast Asian Nations (ASEAN). The economy is divided into two regions: West Malaysia – also known as Peninsular Malaysia, which is located on the peninsula sharing its northern border with Thailand – and East Malaysia, which shares borders with Indonesia; Brunei Darussalam. The states of Labuan, Sabah and Sarawak are situated in East Malaysia. Major cities such as Kuala Lumpur and Johor Bahru are located in Peninsular Malaysia (or West Malaysia), which is also the economic hub of the economy. Malaysia's per-capita electricity use is among the highest in the Southeast Asian region (Lu et. al. 2021).

The energy sector plays an important role in Malaysia's economy. About 28% of Malaysia's GDP comes from the energy sector (PwC 2023, p. 4). Malaysia has been considered as being rich in fossil-fuel energy sources including oil, gas and coal. In 2020, natural gas accounted for 42% of total energy supply, followed by crude oil and petroleum (IRENA 2023).

Malaysia has become a major oil and gas importer, making its economy vulnerable to supply shocks. To mitigate this, Malaysia has taken important steps to expand the use of RE alternatives. According to the Malaysian Investment Development Authority (MIDA), Malaysia aims to achieve 31% RE capacity by 2025, 40% by 2035 and 70% by 2050 (MIDA 2021). Malaysia's renewable energy transition encompasses investments in solar, wind, hydro, and biomass energy projects. The economy's abundant sunshine makes it particularly suitable for solar energy generation, while wind resources in certain regions hold great potential. Malaysia is exploring opportunities to harness its vast palm oil industry for biomass energy production. Transition towards RE based electricity supply is critical for Malaysia to realize the Twelfth Malaysia Plan (2021-2025) target of achieving net zero greenhouse gas emissions by 2050 and the 2022 National Energy Policy goal to be a low carbon economy by 2040.

4.1.2. Understanding Malaysia's energy market

Regulatory oversight

Malaysia's energy sector is regulated by the Ministry of Energy and Natural Resources and managed by various agencies and companies responsible for electricity generation, transmission, and distribution. The Energy Commission (Suruhanjaya Tenaga) plays a crucial role in regulating and supervising the electricity and gas supply industries.

Energy generation and distribution

Malaysia's energy market has evolved to incorporate both public and private sector participation. The generation sector consists of both public suppliers and private IPPs. Electricity generation is dominated by the three state-owned power producer companies: Tenaga Nasional Berhad (TNB), Sabah Electricity Sdn Bhd (SESB) and Syarikat SESCO Berhad (SESCO). TNB is the main electricity supplier for Peninsular

Malaysia while East Malaysia is covered by SESB (Sabah) and SESCO (Sarawak) (Marc Ratings Berhad 2022). Since 1992, part-liberalization reforms have allowed IPPs to participate in generation. Today, Malaysia's energy market follows a single buyer model in which the Single Buyer – a ring-fenced department within TNB – procures electricity from generators such as IPPs and TNB itself (Kumar et. al. 2021).

While generation assets can be owned by the private sector, transmission and distribution network assets remain state-owned assets and are monopolized by TNB. The TNB-owned Single Buyer oversees the dispatch and price settings of electricity generation. Generators sign PPAs with the Single Buyer which specify a fixed-commercial rate for energy supply. The Single Buyer would then dispatch electricity based on a least-cost principle which dispatches electricity from suppliers that have agreed to the lowest rate first, followed by the second cheapest unit, until all energy demand is met (Sibeperegasam et. al. 2021). Since the 2015 New Enhanced Dispatch Arrangement (NEDA), non-PPA generators can also sell energy to the Single Buyer. This arrangement is suitable for small RE generators. Under the NEDA, generators are paid based on the Higher of Forecast or Actual System Marginal Price (SMP), no bid is required – the generator submit planned generation for the next trading day. They are paid at the Higher of Forecast or Actual SMP multiplied by metered output and capped at registered capacity. SMP is defined as the price of the most expensive marginal generator scheduled or dispatched to meet demand and is determined every half-hour.

4.1.3. Benefits of EES

The Malaysian government has set an ambitious target of RE providing 31% of the economy's energy needs by 2025 and 40% by 2035 under the Malaysia Renewable Energy Roadmap. Malaysia has made various domestic and international climate commitments. In 2016, Malaysia ratified the Paris Agreement, aiming to achieve net zero emission by 2050. Under the 2022 National Energy Policy, Malaysia announced the goal to be a low carbon economy by 2040. These climate commitments require a substantial roll-out of RE. Due to its added values in facilitating VRE adoption, EES could be an important tool that could help Malaysia to realize its climate commitments.

Reduce energy curtailment

Malaysia's growing economy, coupled with increasing urbanization and industrialization, has led to a surging demand for electricity, especially electricity generated from RE sources. PV technology is regarded in Malaysia as the major source of RE generation to sustain an increasing energy demand in years to come (MIDA 2021). Due to solar PV output not being able to adjust to meet demand, Malaysia has adopted initiatives to enable use of excess electricity generation. For example, under Malaysia's Net Energy Metering scheme, all consumers are entitled to a one-to-one offset basis in which 1kWh generated from the PV will be offset against 1kWh consumed from the grid system. This allows for excess solar energy to be exported back to the grid in exchange for financial incentives. However, based on the NEM requirements, there is an export limit imposed for consumers whose capacity installation of the solar PV is greater than 72 kW (Lee 2023). Behind-the-meter EES provides a better solution to handling excess electricity in large-scale power generation systems.

Enhance grid stability

High electricity demand poses a risk to stable power supply in Malaysia, potentially causing outages that impact its economy. In some regions, energy capacity is limited with low reserve margins, especially during peak times. ESS such as BESS can serve as interim emergency power sources in these regions during outages, help to alleviate grid congestion and address issues related to intermittent power supply.

Reduce electricity costs for users

High electricity prices are described as an obstacle to Malaysia's industrialization process. Malaysia's economic development depends greatly on the energy sector. It is projected that electricity demand per capital in 2040 will be 7445kWh, up 50.3% from the demand in 2020 (Azman et. al. 2021). In dealing with high demand during peak periods, peak power plants are required to provide additional electricity. These peak power plants have high operational costs, partially due to additional costs for extra fuels. To recover such costs, utility companies often charge consumers a premium price based on the maximum demand during the billing cycle (Chua et. al. 2015). By allowing users to store energy for future use, EES technologies ease the stress of peak demand in Malaysia, helping to reduce electricity price. An example of how behind-the-meter storage can benefit consumers is the 400 kW/667 kWh EES system commissioned at a university building in the Universiti Tunku Abdul Rahman, which has generated annual savings of around USD 3,800 in the department's electricity bills (Lim et. al. 2019).

4.1.4. Existing, planned and potential EES projects

EES is still a new technology in the Malaysian energy sector, with most installed capacity in BESS or small-scale and off-grid systems. There are five units of BESS deployed as research projects at distribution level positioned in various locations such as research centers, education campuses, commercial centers and universities.

According to the National Energy Transition Roadmap, the long-term objective for Malaysia is to develop utility-scale ESS to accommodate higher levels of renewable energy, a goal to be championed by the Ministry of Natural Resources and Environmental Sustainability and the Energy Commission (Ministry of Economy 2023). The Malaysian Grid System Operator, in partnership with TNB, plans a trial project for grid-connected BESS, with full-scale grid integration anticipated by 2030 (Razif 2024).

To further ESS deployment, Malaysia's public and private sectors are collaborating on new BESS business models and demonstration projects. In May 2023, Citaglobal Genetec BESS, a joint venture between Citaglobal and Genetec Technology, introduced the economy's first in front of the meter BESS system, known as the one-megawatt-hour Battery Energy Storage System (Orissa International 2023). In Sabah, the Energy Commission has issued a procurement tender for a 100 MW standalone BESS installation.

Modelling done by Blakers et. al. (2021) shows that Malaysia has the potential to store around 120,000 gigawatt-hour (GWh) of electricity in PSH systems. However, there is currently a lack of existing and planned PSH electricity storage systems in Malaysia at the economy-wide and large-scale levels (APEC 2022). PSH development has been limited due to perceptions of its complexity compared to battery systems, as well as the fact that states do not have jurisdiction over water. This makes it difficult for state governments such as in Sabah to initiate PSH since it can only be implemented by the central government.

4.1.5. Assessment of Malaysia's EES market setting

Regulatory framework

According to MyRER, the Malaysian government will begin prioritizing energy storage solutions after 2025, with initial actions focused on evaluating EES' role in maintaining system stability (SEDA, 2021). The National Energy Transition Roadmap highlights plans to develop storage facilities within 2,500 MW of hybrid hydro-floating solar installations at TNB hydro dam reservoirs.

Specific targets for energy storage assessment and adoption are set at the regional level. Under the Peninsular Malaysia Generation Development Plan 2020, Peninsular Malaysia targets the installation of 500 MW in energy storage capacity between 2030 and 2034 (Energy Commission 2021). In Sabah, the short-term goal, as outlined in the Energy Roadmap and Master Plan 2040, includes exploring BESS to diversify the energy mix. From 2023 to 2025, plans are set to develop 120 MW of new BESS capacity on the East Coast. In the longer term, utility-scale storage potential will be further assessed as the technology becomes economically viable to support electricity transmission from the West Coast to the East Coast of Sabah, alleviating power supply issues in the eastern region (Energy Commission of Sabah 2023).

While there are no current mandates for EES technologies, solar plants are strongly encouraged to incorporate BESS with a minimum one-hour full export capacity to enhance solar energy use, mitigate intermittency and improve energy management (Single Buyer 2023). Despite encouragements, private developers are still unwilling to invest in BESS due to the high costs, necessitating other policies such as financial support.

Financial support

Common EES technologies, such as BESS and PSH, remain costly and relatively high-risk investments in Malaysia. Consequently, private sector involvement in these technologies is still limited, with much of the funding expected to come from government sources in the near term. Collaborative initiatives with other economies are underway to support EES technology development. For example, in 2023, Masdar – a subsidiary of the UAE state-owned Mubadala Investment Company – signed a memorandum of understanding with MIDA to invest USD8 billion to develop up to 10GW of renewable energy projects (including energy storage) in Malaysia (MIDA 2023). In 2019, Malaysia and Republic of Korea partnered to invest around USD7 million to the pilot project for Virtual Power Plant technology which involved the installation of four BESS systems with a total of 2 MW capacity (AEDS n.d.). These investments highlight some government-led efforts to support EES development financially.

There are several direct financial incentives available for investors in battery energy storage technologies. Through the Green Investment Tax Allowance and the Green Income Tax Exemption schemes, qualifying investors can benefit from tax allowance on capital expenditure for BESS installations (MGTC 2022). Indirect incentives, such as the Green Technology Financing Scheme and preferential loans from local banks, also provide low-interest financing options that, while not explicitly for EES, could indirectly boost its adoption.

Market mechanisms

Energy arbitrage

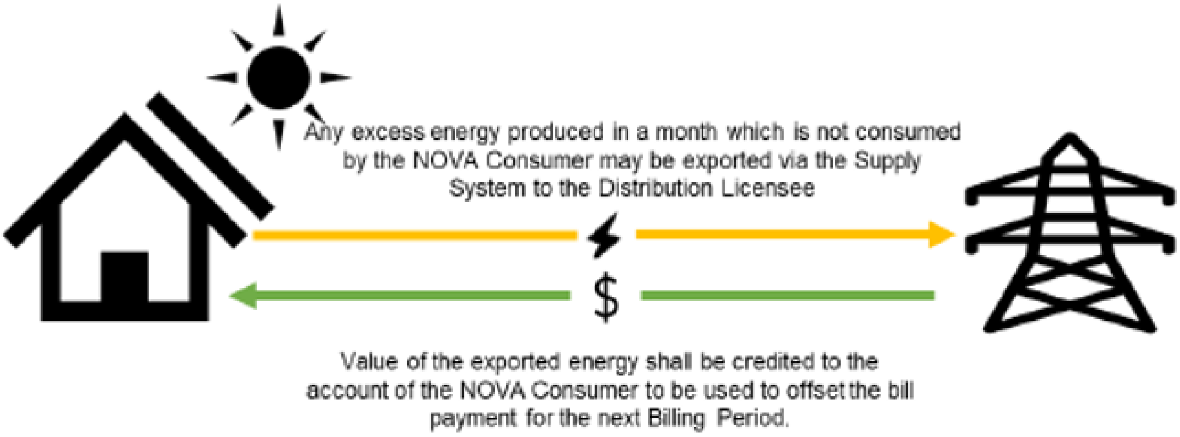
The 2015 NEDA allows RE generators to sell electricity to the Single Buyer without a PPA, receiving payment based on the higher value between the Forecast or Actual System Marginal Price. NEDA can incentivize the use of EES technologies by enabling generators to store excess energy during off-peak hours and deploy it during peak hours when rates are higher, potentially driving interest and investment in energy storage. However, NEDA remains a small market, largely due to limited incentives to join, as the government regularly issues PPAs. While some generators may still opt to join NEDA for additional income beyond their PPA-guaranteed revenue, the current 100 MW capacity limit restricts both participant numbers and market opportunities for energy arbitrage.

Market signals

A potential investment signal for EES investment in Malaysia is the Net Offset Virtual Aggregation Virtual Power Plants (NOVA-VPP). Under the NOVA-VPP, electricity generators can export any excess stored energy within a month under a special billing based on the Average SMP. Figure 8 documents how NOVA-VPP works for two categories of consumers (Category A and Category B). This allows investors of EES technologies to generate income through energy arbitrage. For example, generation from PV could be stored during low marginal price (off-peak) or non-peak hours and exported back to the grid to offset the bill payment for the next billing cycle when the SMP is high. The value of the exported energy shall be credited to the account of the NOVA Consumer to be used to offset the bill payment for the next Billing Period. NOVA-VPP makes it possible for EES owners to pay a lower energy charge – calculated as followed:

Net Energy charge (RM) = (Energy imported from Supply System x prevailing gazetted Energy rate) – (Energy export to Supply System x Average SMP)

Category A:



Category B:

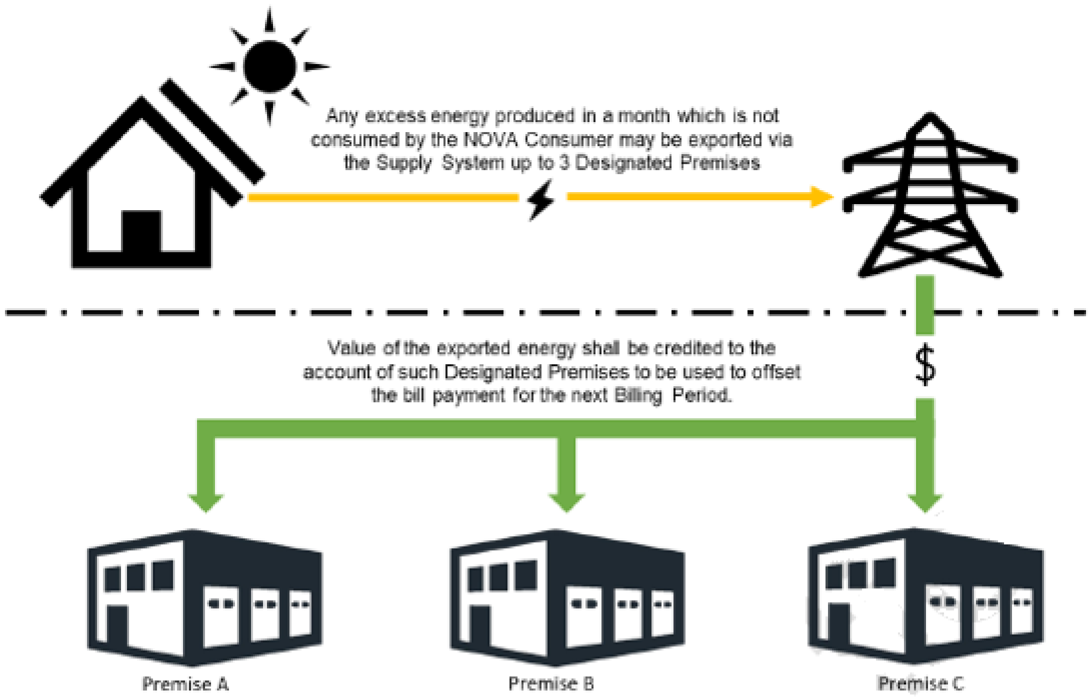


Figure 8: Remuneration schemes under NOVA-VPP for Category A and Category B

In a VPP case study, for a Malaysian commercial load under the Medium Voltage Peak/Off-Peak Commercial Tariff with monthly peak demand of 500 MW under the VPP scheme would have a 4.3% rate of return within the period of 10.5 years through peak reduction and energy arbitrage (Abdullah et. al. 2021).

However, the NOVA Contract only lasts for a period of 10 years. After that, the solar PV installation shall be strictly for self-consumption. Given the long lifecycle of large-scale EES technologies such as PSH which can last more than 50 years or BESS which lasts between 8 to 15 years, NOVA-VPP may not constitute a reliable investment signal to promote private investment in EES technologies.

Ancillary services

In terms of ancillary service markets, grid-scale EES in Malaysia, particularly BESS, can provide services such as voltage support, frequency regulation, spinning reserve and black-start capabilities (Abdullah et. al. 2021). Many of these services are remunerated. For example, documents that BESS can potentially serve the Grid System Operator for spinning reserve, frequency regulation, voltage support and black start. However, these services are currently contracted through PPAs with generators rather than through an open market, as seen in economies like Australia. There is limited information regarding how these ancillary services are priced within PPAs, which may hinder broader participation in ancillary service markets. In the case of Peninsular Malaysia, MyPOWER corporation is working on a roadmap aimed at developing more structured mechanisms for ancillary service markets, though the timeline for its completion remains uncertain.

4.2. Papua New Guinea

Key findings – Papua New Guinea

- Papua New Guinea faces significant energy challenges despite its abundant natural resources. The economy's geography, with more than 600 islands, dense rainforests, and rugged terrain, presents obstacles to grid connectivity. This has resulted in limited access to electricity, especially in rural areas.
- The National Electrification Roll Out Plan aims at 70% electrification by 2030 and 100% by 2050. While oil, gas, and hydropower have traditionally dominated the energy sector, RE sources like solar, wind, hydro, geothermal, biomass, and tidal wave have gained attention due to sustainability and cost considerations.
- The regulatory oversight of Papua New Guinea's energy sector is situated with the National Energy Authority, responsible for implementing the National Energy Policy. The state-owned company, PNG Power Limited (PPL), plays a central role in the electricity supply, operating both on-grid and off-grid generation.
- EES is crucial to improving grid electricity reliability, strengthening off-grid access, and reducing electricity costs. PPL has turned to independent power producers to help meet energy demand, with EES technologies being pivotal in integrating RE into the energy mix.
- Current plans in Papua New Guinea involve projects like the National Energy Access Transformation Project, which aims to establish micro-grids with solar and hydropower combined with battery storage. International support from organizations like the Asian Development Bank and the World Bank is instrumental in implementing these electrification projects.
- While Papua New Guinea has the potential for PSH, no such projects are currently planned or operational.
- Plans to fine tune
- Feed-in-Tariff schemes could incentivize EES development and investment, but the details are yet to be developed. Public-Private Partnerships and PPAs could provide an investment signal for private investment in EES technologies.

4.2.1. Economy background

Papua New Guinea has vast geography with a population of approximately 9 million people – 85% of them living in rural areas (DFAT n. d., and World Bank n. d.). Occupying the eastern half of the island of New Guinea and its offshore islands, the economy has 22 provinces in 4 major regions: central Highlands Region, Island Region, Momase Region and Southern Region.

Located in an active volcanic zone, Papua New Guinea is rich in natural resources including significant oil reserves. The economy has abundant RE resources such as hydro, geothermal, biomass, solar, wind and tidal wave (Lahan et. al. 2020). However, much of Papua New Guinea's potential remains untapped and it is the least energy intensive economy in the APEC region (APEC 2016). According to data from the United Nations Development Programme, less than 15% of Papua New Guinea's population have access electricity. In rural areas, electricity access is under 3.7% (UNDP, n. d.).

Under the National Electrification Roll Out Plan (NEROP), Papua New Guinea sets the goal of achieving 70% electrification by 2030 and 100% electrification by 2050. However, Papua New Guinea's geography which includes more than 600 individual islands with steep elevations and thick rainforest cover across the main island poses a significant challenge to building grid connectivity. As an alternative to grid electricity access, many communities in remote areas rely on off-grid electricity generation. The sales of off-grid solar products have grown steadily and are continuing to grow to meet electricity demands (USAID 2022).

Oil, gas and hydropower still dominate on-grid electricity production in Papua New Guinea – many of the economy's largest energy companies are oil and gas producers. Biomass and geothermal also constituted a notable portion of electricity production between 2004 and 2012, primarily for use in resource mining and processing industries. With the rising cost of oil, RE has become more attractive as a solution to meeting future electrification goals. The added values of RE range from using solar power for basic applications such as phone charging and lighting of rural households to harnessing biomass and geothermal electricity generation for energy-intensive industries such as agricultural processing and resource extraction – industries that are crucial to Papua New Guinea's economic development.

4.2.2. Understanding Papua New Guinea's energy market

Regulatory oversight

Papua New Guinea's energy sector has undergone significant reforms in recent years. In 2015, the Papua New Guinea Government unveiled the National Energy Policy (NEP) which established the National Energy Authority (NEA). The NEA is responsible for the development and implementation of a NEP and the implementation of NEROP. The 2021 NEA Act further expanded the purpose of the NEA to serve as an umbrella agency for establishing service standards for transmission and distribution networks, setting electricity tariffs, service quality standards, regulating and issuing licenses and permits to electric sector participants and enforcing electrical standards and license conditions.

Energy generation and distribution

Papua New Guinea's electricity access can be classified into either on-grid or off-grid access. Access to the transmission grid is only available in some major urban and industrial centers. There are three major grid systems in the economy: the Port Moresby System, the Ramu System and the Gazelle Peninsula System. The Port Moresby System serves the capital city of Port Moresby and other parts of the Central Province. The Ramu system serves the economic and industrial load centers in the Momase Region and the Highlands Region. Communities that are not connected to any of the three major grids but have high and concentrated electricity demand can access smaller grids or mini-grids. There are 26 mini-grids across Papua New Guinea (USAID 2024).

The state-owned vertically integrated electricity company, PPL, plays a major role in supplying and transmitting grid electricity through the three major grids and 26 mini-grids. PPL operates over 300 MW of on-grid and approximately 100 MW of mini-grid generation (USAID 2022). However, PPL's financial standing makes it challenging to meet investment needs for the multiple mini-grids that require significant refurbishment (Nepal et. al. 2022). The company partly relies on independent power producers (IPPs) and private sector generators to supply energy to mini-grids. Under this arrangement, PPL operates as a single buyer and purchase hydro and thermal generated electricity from IPPs through long-term PPAs.

In rural areas where energy demand is not sufficiently concentrated for grid installations to be viable (for example, due to small population size or limited institutional demand), the energy market is characterized by off-grid access. Households and businesses generate electricity using standalone residential solar systems or Solar Home System (SHS) and other productive energy products. In these settings, SHS are often the least-cost option for households because their total lifetime cost is lower than alternatives. Trained on-site professionals are not necessary to install SHS as such products afford customers the ability to "plug and play." An estimated 60% of the Papua New Guinea's population owns at least one off-grid solar product. This number varies by province, with more off-grid product ownership in the Islands Region and less in the Highlands Region (USAID 2022). The renewable off-grid market has high potential due to the widespread availability of solar and hydropower resources across the economy.

International supports

Papua New Guinea receives assistance from various international bodies in rolling out many electrification projects. For example, the Asian Development Bank (ADB) and the World Bank are supporting most of the ongoing electricity improvement programs in Papua New Guinea (Rawali et. al. 2020). Australia's Department of Foreign Affairs and Trade (DFAT), through the Economic and Social Infrastructure Program and Australian Infrastructure Financing Facility for the Pacific, also support the Papua New Guinea Government in providing energy (on-grid and off-grid electrification) infrastructures.

4.2.3. Benefits of EES

EES plays an important role in helping Papua New Guinea achieve widespread, reliable and affordable electricity access – the three strategic objectives of the government under the Electricity Industry Policy.

Improve grid electricity reliability and stability

Currently, Papua New Guinea's grid and mini-grids lack generation capacity, have limited coverage and low quality of service. Power outages are an ongoing issue for communities which have access to grid electricity, even in urban areas. The lack of reliable access to electricity is detrimental to Papua New Guineas economic development goals such as the Papua New Guinea Development Strategic 2010–2030 which aims at "high quality of life for all" and "economic prosperity of Papua New Guinea by 2030" (Department of National Planning and Monitoring 2010) In a 2015 World Bank survey, 11.5% of small businesses (out of the 4.2% of all firms surveyed in Papua New Guinea) reported that electricity was their main obstacle (World Bank 2015). With their ability to store excess electricity and provide uninterrupted power supply when discharged, grid-scale EES technologies can play a vital role in Papua New Guinea's efforts to provide reliable grid electricity, especially in areas with limited access to consistent power.

Strengthen off-grid electricity access and quality

In rural areas where grid electricity is inaccessible, power disruptions pose an even bigger problem. Off-grid systems such as SHS have low reliability. According to USAID, users of these systems can experience more than 14 disruptions per week which potentially damage appliances (USAID 2022). Low quality of power threatens the operation of sectors that are crucial to the economic and human development of rural communities in Papua New Guinea. EES such as BESS can be deployed to provide off-grid solutions, making electricity more accessible to these areas and improving the quality of life for their residents. According to NEROP, SHS requires a series of storage batteries meet supply during periods of low sunshine intensity or after sundown. The batteries may be either conventional lead acid or in the future may include the next generation of NiCad or Lithium–ion storage batteries (The Earth Institute Economic Consulting Associates, 2017).

As a case study, the Madan Medical Clinic and Birthing Centre is a health facility which serves between 12,000 and 15,000 patient visits, 5,000 vaccinations and hundreds of births every year. Its power generation is completely off-grid, utilizing PV sources. However, EES capacity would be required for vaccine refrigeration, powered medical tools, surgical instrument sterilization, nighttime delivery and trauma services and computer-based reference guides for clinic staff (Anderson and Podmore 2016).

Reduce electricity costs

Average residential electricity prices in Papua New Guinea were among the highest in the world with a price of USD 0.39/kWh between 2010 and 2015 as the economy primarily relies on a high-cost diesel generation (Nepal et. al. 2022). The declining costs of solar PV plus battery storage systems make them an attractive alternative mode of generation compared to diesel from the point of view of both utility companies and end-users. The 26 mini-grids run on diesel or a combination of hydro and diesel generators. All of them operate at significant losses due to high diesel costs. Partial substitution of diesel or combining wind with gen-sets (wind-diesel hybrid) and some form of RE storage such as PSH could cut down on running or overall costs (Department of Petroleum and Energy n.d.). EES, especially BESS, supports cost savings for end-users such as households by allowing them to produce and consume their own electricity. Studies have shown that, for a village setting, solar PV with storage is almost 50% cheaper than diesel (Rawali et al. 2020). By lowering system costs, development of EES technologies has the potential to significantly boost electricity usage in low-income and rural communities, contributing greatly to Papua New Guinea's electrification goals under NEROP.

4.2.4. Current plans

EES and PSH are new technologies in Papua New Guinea. There are few on-going and planned EES projects in Papua New Guinea. Most of them support the concurrent deployment of off-grid solar products and EES rather than being standalone EES systems. Table 7 summarizes some key EES projects in Papua New Guinea.

Table 7: Key EES projects in Papua New Guinea

Project	EES-related target	Status	Note
National Energy Access Transformation Project (NEAT)	Establish micro-grids to utilize solar and/or hydropower combined with or without battery storage, and have a capacity of maximum 1 MW	Ongoing	Financed by the World Bank and executed by NEA and PPL
9MW Solar + 2 Hr Battery Storage in Markham	N/A	N/A	Financed by DFAT and ADB
PNG Biomass' projects	Provide the Ramu grid with up to 40MW of RE with the BESS providing firming and grid stabilization services.	N/A	Power purchase agreements with PPL
Gelion–Mayur Renewables clean energy projects	Deliver 100 MWh of energy storage to Papua New Guinea's energy supplier Mayur Renewables	N/A	Provided by Australian-UK energy storage innovator Gelion.

Project	EES-related target	Status	Note
Aitape Solar Hybrid System	A 750 kW hybrid solar PV system with BESS integrated	Completed	Financed by DFAT and Papua New Guinea's Economic and Social Infrastructure Program; supervised by University of Papua New Guinea Centre of Renewable Energy

While Papua New Guinea's mountainous terrain provides natural elevations are ideal for PSH, the technology has not yet been adopted in Papua New Guinea. The height differences between mountain valleys and rivers make it possible to create efficient high-head storage systems, reducing the infrastructure needed to achieve effective energy storage. Coupled with the abundance of rivers, lakes, and rainfall, especially in regions with dense tropical forests, PSH holds promising potential. Blakers et. al. (2021) estimates that Papua New Guinea has the potential to store around 392,000GWh of electricity in PSH systems.

There are multiple off-grid EES projects, deployed in combination with solar systems (using batteries in behind-the-meter system). For example, the Enga Provincial Government finances an 80-kilowatt hybrid mini-grid, combining solar panels, batteries, and diesel generators, to supply power to the Kompiam hospital and its associated staff housing (USAID 2022). The Australian government's Economic and Social Infrastructure Program (ESIP), under its off-grid component Pawarim Komuniti, lends support to the enhancement of PPL mini-grids in Maprik, Finschhafen, Vanimo, and Daru, transitioning them into solar-battery-diesel hybrid systems. ESIP has also initiated the tendering of feasibility studies for upgrades at two of these locations to advance them towards the construction phase.

4.2.5. Assessment of Papua New Guinea's EES market setting

Regulatory framework

Papua New Guinea's current energy regulatory framework prioritizes achieving 70% electricity access as a primary objective. Regulations on solar energies and EES, particularly BESS, are viewed as long term priorities. At present, there are no specific regulations on the adoption of EES such as economy-wide or regional targets or mandates for EES capacity. However, the NEA is fine-tuning guidelines for on-grid PV systems with BESS, funded by the ESIP for PPL, though regulatory responsibilities have since transferred to NEA. Papua New Guinea also plans to explore regulations such as licensing for EES through pilot projects, assessing each case individually.

Financial support

In Papua New Guinea, EES projects are financed by a combination of government investments, international collaborations and international aid such as through the ADB, World Bank, DFAT's ESIP and USAID's PNG Electrification Partnerships. Currently, in Papua New Guinea, an estimated PGK16- 17 billion is projected to potentially fund upcoming EES projects, though this figure remains a preliminary forecast based on current demand and could vary by approximately 30%.

While EES projects in Papua New Guinea are expected to rely primarily on government and international funding in the near term, efforts are underway to encourage private sector participation through financial incentives for public-private partnerships. The 2024 National Energy Access Transformation Project offers capital subsidies to encourage private investment in mini-grid assets managed by PPL (PPL 2024). This includes subsidies for private investments in a new solar PV system with BESS. Papua New Guinea has special funds like the Pawarim Komuniti Program, which offers grants to high-quality projects focusing on local off-grid energy solutions, including battery storage options.

Market mechanisms

Energy arbitrage

There is limited scope for energy arbitrage in Papua New Guinea since energy generated by the private sector are still procured by the PPL primarily through PPAs.

Investment signals and ancillary services

In Papua New Guinea, IPPs can generate and supply energy to PPL which can then be sold to customers under PPAs. PPAs are long-term contracts which can act as investment signals for EES adoptions. However, terms and conditions of the contract has not been made public and its impacts on providing effective investment signals for EES private investors are yet to be seen (Independent State of Papua New Guinea 2011).

The Government of Papua New Guinea explores different models of Public Private Partnerships (PPPs), such as service-operate-transfer or build-operate-transfer, which are expected to have a duration of 20 to 30 years (ADB 2020). Papua New Guinea embraces PPPs as a means of addressing gaps in infrastructure and public service delivery. Over time, numerous projects have emerged involving both public and private sector entities. All PPPs are established through a competitive bidding process and subject to scrutiny by the relevant regulatory bodies (Department of Petroleum and Energy 2017). The government currently maintains a National PPP policy to provide guidance for such decisions, and the implementation of the NEP will align with this established policy framework. It remains to be seen whether the Papua New Guinea will utilize PPPs to procure EES projects.

A key market signal highlighted in the National Energy Policy (NEP) 2017–2027 is the Feed-in Tariff (FIT) scheme for RE generators, which could support the development of EES. The FIT scheme is intended to encourage investment in renewable energy by offering fixed electricity prices to RE producers for each unit of energy they produce and inject into the grid. This fixed payment is guaranteed for a period typically aligned with the project's economic lifetime, often between 15 to 25 years, offering revenue stability for potential EES investors throughout most of the project's operation.

The FIT scheme may include bonuses for ancillary services, creating further incentives for storage solutions that contribute to grid stability. However, the operational details and regulatory framework required to fully activate the FUT scheme under the NEP are still under development. A challenge to the development of the FIT scheme is the information asymmetry between the public and private sectors due to the lack of monitoring mechanisms to determine the appropriate remuneration levels (Department of Petroleum and Energy 2017).

4.3. Thailand

Key findings – Thailand

- Despite being rich in natural gas, Thailand heavily relies on imported fuels making it vulnerable to supply shocks. The economy's commitments to tackle climate change has further driven its interest in renewable energy. Thailand ratified the Paris Agreement and has pledged to reduce its greenhouse gas emissions by 30% from projected levels by 2030.
- The regulatory oversight of Thailand's energy sector falls under the Ministry of Energy, with the National Energy Policy Council responsible for setting policies and tariff structures. The Electricity Generating Authority of Thailand manages the transmission system and dominates the wholesale electricity market. Private power producers have been encouraged to enter the market since 1992.
- EES, particularly BESS and PSH, offer several advantages in Thailand. They facilitate the adoption of rooftop PV systems, enhance system reliability, and reduce electricity costs, especially during peak demand periods.
- Thailand has plans to expand its EES infrastructure, with a significant focus on PSH. Several PSH projects are in operation or development, making Thailand the ASEAN leader in PSH capacity. The government aims to promote smart infrastructure and EES for energy independence and renewable energy transition.

4.3.1. Economy background

According to the International Energy Agency, on average in the past 20 years, Thailand's per-capita electricity consumption ranks fourth across all Southeast Asian economies. Most of Thailand's electricity generation comes from natural gas and coal (Figure 13). However, Thailand relies largely on imported fuels – especially imported crude oil and natural gas (Kamalad 2021). In 2017, more than one-half of Thailand's total final energy consumption was met by imported energy sources (IRENA 2017). The combination of high dependence on import and the energy-commodity price volatility caused by today's unstable international political landscape poses a profound energy security challenge for Thailand. This calls on the need to diversify the energy mix and RE is seen as an answer. Thailand's first recorded renewables electricity generation was in 198. but it was not until 2003 that the percentage of renewable generation in Thailand's energy mix rose above one percent of the total, after which it has grown to reach 10% in 2019.

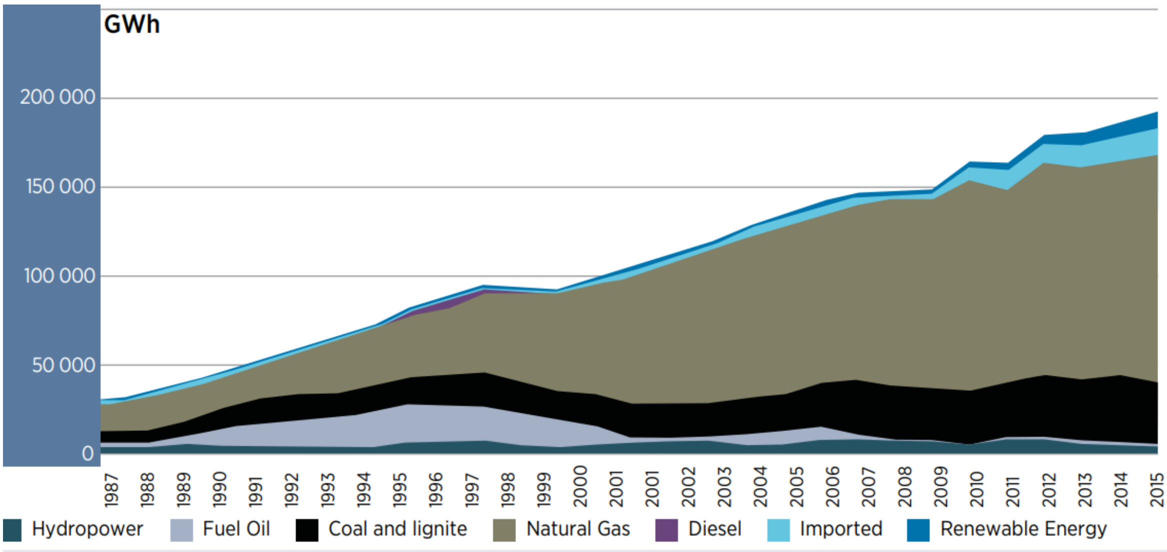


Figure 2: Thailand's energy supply (1987-2015)

Thailand has made various commitments, both domestic and international, to increase the use of RE to tackle climate change. In 2016, Thailand ratified the Paris Agreement with a long-term goal of moving towards net-zero greenhouse gas emissions. Under its Nationally Determined Contribution to fulfill this long-term goal, Thailand pledged to reduce it greenhouse gas emission by 30% from the projected business-as-usual level by 2030 (UNFCCC 2022). Thailand, alongside other ASEAN Member States, endorsed the ASEAN Plan of Action and Energy Cooperation Phase II: 2021-2025 with the theme "Enhancing Energy Connectivity and Market Integration in ASEAN to Achieve Energy Security, Accessibility, Affordability and Sustainability for All."

Domestically, Thailand is implementing the Climate Change Master Plan 2015-2050 which is designed to establish a forward-looking path that various governmental bodies and sectors can follow to shape their respective strategic action plans. In 2019, Thailand announced the Power Development Plan for 2018-2037 with the goal of achieving a 35% RE share in total power generation capacity by 2037.

4.3.2. Understanding the energy market of Thailand

Regulatory oversight

Thailand's energy sector is governed by the Ministry of Energy and managed by the National Energy Policy Council (NEPC) which is responsible for enacting economy-wide energy policies and establishing the tariff structures for energy sales (ADB 2019).

Generation and transmission

The Thai energy sector follows the enhanced single-buyer model. The Electricity Generating Authority of Thailand (EGAT) – an SOE – manages the transmission system and holds a monopoly on high-voltage transmission and wholesale electricity market. This means that EGAT is the only organization that can purchase wholesale electricity or resell to other distributors. EGAT's generation capacity accounted for 34% of Thailand's total electricity generation capacity as of the end of 2022 (Thailand Board of Investment 2023).

Since 1992, Thailand has encouraged private power producers to enter the energy generation market. EGAT is the main purchaser of bulk electricity from private power producers – including IPPs, small power producers (SPPs) (whose capacities range between 10–90 MW) and neighboring economies (IEA 2020). The capacity constraint of an IPP is 90 MW. As the single buyer, EGAT purchases bulk electricity from 12 IPPs, totaling 17,648.5 MW and a total of 9,483.37 MW from SPPs (EGAT 2024). Such purchases are procured through long-term PPAs, generally lasting between 20 to 25 years and the prices were determined by negotiations between EGAT and the IPPs.

Projects generating up to 10 MW can sell their power to the Metropolitan Electricity Authority or the Provincial Electricity Authority through the Very Small Power Producer program. Electricity purchased under this program were paid with a FIT. The calculation of the FIT is comprised of three parts: a fixed FIT (THB2.39 – 6.85 per kWh – applicable for all energy types), a variable FIT (THB2.69 - 3.21 per kWh - applicable only to certain fuels), and a premium (THB0.5 – 0.7 per kWh - applicable for waste, biomass, biogas or projects located in three southern provinces of Thailand). Renewable energy SPPs and VSPPs are entitled to receive a financial incentive, commonly referred to as the "adder" on top of the standard FIT (Supriyasilp et al. 2017).

4.3.3. Benefits of EES

Assist the widespread adoption of rooftop PV systems

In recent years, the Thai government has begun promoting self-consumption rooftop PV systems. The Alternative Energy Development Plan 2015-2036 aims to achieve 6000 MW of installed rooftop solar PV by 2036 (Ministry of Energy 2015). Since PV generation peaks around noon, excess energy is often produced during the day. With BESS, this electricity can be used on-site, with any surplus fed back into the grid.

Ensure system reliability

In 2016, the Thai government enacted a self-consumption scheme for PV generation compensation. Under this scheme, excess energy generated by PV can be repurchased at a buyback rate, thus reducing the cost of PV installation and incentivize its use (Chaianong et. al. 2019). Even though these schemes are expected to increase the profitability of rooftop PV investment, they increase the imbalance between load and generation profiles and the need for network investments (Chaianong el. al. 2020). Meanwhile, integrating batteries with PV systems has the potential to alter the distribution of power demand, resulting in decreased generation during peak hours, which can provide more long-term benefits to the Thai electricity market.

Reduce electricity costs

Due to its efficient use of cheaper generation during off-peak periods and discharges during more expensive on-peak periods, BESS have potential to reduce the operational costs of PV. Modelling done by the International Energy Agency shows that installing a 400 MW battery would save THB 75 million in operational costs. In the North-eastern region specifically, an additional 400 MW battery capacity (total of 800 MW) can generate an additional THB 122 million (IEA 2021). While the savings are still small compared to the investment costs, the use of storage leads to less energy being wasted. The LCOE with storage is still lower than without storage when the curtailment rate is high. Kan et. al. (2018) calculates that with a 5% curtailment rate, the LCOE per kWh of a solar PV plant without storage in Thailand is USD 0.163, compared to USD 0.112 of LCOE with battery and USD 0.124 of LCOE with PSH. As the curtailment rate increases to 40%, PSH becomes more cost-effective with a USD 0.134 LCOE, compared to a USD 0.233 LCOE with no storage and USD 0.177 with battery (Kan et. al. 2018). If Thailand installs 800 MW of new PSH in 2030, the system's annual operational costs could be reduced by about THB 60 million.

4.3.4. Current plan

There are two EES technologies that have been adopted by Thailand: BESS and PSH. By 2022, around 333.92 million kWh or 0.17% of electricity in Thailand is supplied by PSH plants (EGAT 2022). Thailand has the largest PSH capacity across all ASEAN Member States (IEA 2020). Thailand has been building numerous hydro-floating solar hybrid plants, including the Sirindhorn Dam – the "world's largest hydro-floating solar hybrid" (EGAT 2021). This opens various opportunities for PSH development. Blakers et. al. (2021) models the PSH storage potential in Thailand to be around 63,000GWh. Table 8 summarizes some of the key PSH projects and their status in Thailand – all of which are owned by the state-owned EGAT.

Table 8: Key PSH projects in Thailand

Project	Capacity (MW)	Status
Srinagarin Dam Unit 4-5	360	Under operation
Bhumibol Dam Unit 8	171	Under operation
Lamtakong Jolabha Vadhana Unit 1-4	1000	Under operation
Chulabhorn PSH Power Plant (3 Units)	800	Feasibility study conducted – pending approval from the government

Project	Capacity (MW)	Status
Srinagarind PSH Power Plant (3 Units)	800	Under feasibility study
Chai Badan Substation	21	Under operation
Vajiralongkorn Dam PSH Plant	900	Under feasibility study

The Energy Regulation Commission (ERC) also cooperated with the US Agency for International Development and the National Renewable Energy Laboratory to conduct research of conducive policies and regulations design for BESS deployment in Thailand.

4.3.5. Assessment of Thailand's EES market settings

Regulatory framework

In Thailand, regulations play a crucial role in the development of EES due to their high costs. While EES projects currently rely heavily on government initiation, there is an expectation that both government and private sector investment will drive EES growth in the future. The goal in the short term is to set up a solid regulatory framework which can be piloted before the private sector is involved.

The Government of Thailand has explored different policy and investment avenues to facilitate the large-scale adoption of EES technologies. According to the ASEAN Green Future Report, "Thailand aims to increase energy independence and promote a transition towards renewable energy through smart infrastructure and energy storage systems" (Thampanishvong et. al. 2021, p. 8). Thailand is making significant progress in promoting energy independence and renewable energy adoption through energy storage technologies, particularly PSH and EES. Each of these technologies has a different function in the grid. While BESS stabilizes in the very short term (solar and wind generation variation), PSH will cover the longer-term variation (day and night).

In terms of targets, Thailand aims to achieve 1,000 MW of solar energy combined with BESS by 2030 under the Power Development Plan (Ministry of Energy 2018). The Energy Policy and Planning Office has prepared a detailed Action Plan (2023-2032) to promote BESS, focusing on increasing government demand, fostering collaboration for BESS manufacturing, developing a supportive legal framework, and promoting research and development for BESS innovations (Chandler MHM Limited 2023).

The adoption of EES in Thailand follows a specific timeline outlined in the Smart Grid Action Plan: Medium Term (2022 – 2031) (Ministry of Energy 2024). The key development milestones and activities under each milestone are outlined in Table 9:

Table 9: Milestone for EES development under the Smart Grid Action Plan: Medium Term (2022–2031)

Timeline	2022 – 2032	2024 – 2026	2027 – 2031	2032 onwards
Development milestone	Testing the EES pilot project in the grid scale	Developing the EES for the transmission and distribution systems	Expanding the results to the Thailand's electricity grid Promoting the BGM EES	Use of all types of EES in the Thailand's electricity grid
Activity	Formulate policies and business models to promote the use of EES at grid scale and behind-the-meter levels Drive progress to meet goals set out in the PDP	Pilot, develop, and install EES in the transmission system	Pilot, development and install EES in the distribution system	Revise or create necessary regulations

Financial support

Thailand's financial support for EES primarily comes from direct government investment, especially for large-scale, grid-connected projects. Currently, all PSH are owned by EGAT and rely on EGAT investments, as PSH remains a high-cost investment. Although costs for PSH can be minimized by using existing reservoirs, expenses for infrastructure like tunnels and power stations remain significant.

While BESS are relatively more affordable, larger projects are still primarily government funded. An example is the 16,000 kW Bamnet Narong BESS system, owned and operated by EGAT (Power Technology 2021). This reliance on public funding highlights the need for additional financial mechanisms to attract private investment in EES, particularly as Thailand aims to expand private sector participation in the energy storage sector.

While specific financial incentives targeting EES remain limited, there are indirect support mechanisms such as tax incentives and subsidies for battery manufacturers and electric vehicle owners, which may indirectly promote EES adoption (Beckstead et al 2024). Similar to Malaysia, Thailand provides loans for green or renewable energy projects which have lower interest rates and longer payback periods including the Thailand Taxonomy from the Bank of Thailand. These favorable loans can promote green projects and, in turn, EES technologies.

Market mechanisms

Energy arbitrage

Thailand's regulations now permit the private deployment of behind-the-meter technologies, including rooftop solar and storage, subject to the ERC's licensing regimes. However, there are limited energy arbitrage opportunities for these privately-owned systems. Historically, the private sector could not sell excess power back to the grid directly (without going through PPAs with EGAT). Under the Third-Party Access Service Code, some private RE projects may be able to join the electricity network systems and sell their energy directly to private consumers, as a pilot (Hunton Andrews Kurth 2024). However, the energy sold back to the grid is still subject to Direct PPAs with the private consumers, which utilise fixed rates instead of time-varying energy prices, limiting the scope of arbitrage for EES investors.

Investment signals

Under the Energy Regulatory Commission's Regulation for Procurement of Renewable Energy (2022-2030), SPP can receive a FIT for ground-mounted solar projects with BESS, according to the following procurement quota (Beckstead et. al. 2023). The FIT enables 1000MW of electricity from Solar + BESS to be purchased from 2024 to 2030 (specific quota for each year is detailed in Table 10). These FIT provide a clear and predictable investment signal, making renewable energy projects paired with EES financially attractive.

Table 10: Procurement quota under the FIT (2024-2030)

Year	2024	2025	2026	2027	2028	2029	2030
Procurement quota	100 MW	100 MW	100 MW	100 MW	200 MW	200 MW	200 MW

The contract format for the Partial Firm for ground-mounted solar energy systems with an energy storage system (Solar + BESS) specifies the following electricity purchasing conditions:

- 9:00 AM – 4:00 PM: The electricity generated and supplied to the grid will be purchased by the utility at 100% of the amount offered in the PPA.
- 6:01 PM – 6:00 AM: The system must be capable of supplying 60% of the contracted capacity to the grid for a duration of 2 hours (60% of Contracted Capacity * 2 hours). The utility will purchase up to a maximum of 60% of the amount offered in the PPA and may dispatch up to the maximum available power.
- 6:01 AM – 9:00 AM and 4:01 PM – 6:00 PM: The electricity generated and supplied to the grid will be purchased by the utility at no more than 100% of the amount offered in the PPA.

Ancillary service

As part of the Action Plan, Thailand is enhancing pricing mechanisms for ancillary service markets. By the end of 2024, the Third Party Access Codes will be implemented, allowing private buyers to purchase electricity directly from renewable energy producers through direct PPAs in a pilot program. The ERC is preparing guidelines for Direct PPAs and setting service fees for the TPA Code for each Distribution Utility. These fees will cover ancillary service charges to help stabilize the grid (Hunton Andrews Kurth 2024). The pilot project is anticipated to launch by March 2025. It remains to be seen whether the remuneration for ancillary services will be significant enough to cover the high investment costs of EES.

5. Information gaps and economy-specific options to encourage additional EES investment

EES technologies are advancing in Malaysia; Papua New Guinea; Thailand. These economies recognize the need for robust market structures and regulatory frameworks to support EES growth. Each has development plans, pilot projects, and aims for policy refinement. Currently, large-scale EES projects are mostly publicly owned, but steps are being taken to attract private investment through market incentives, energy arbitrage, and compensation for ancillary services. However, further development of technology and regulatory frameworks will require addressing key information needs and policy gaps to drive EES investment. This section highlights information needs and policy gaps for each economy and outlines economy-specific options to strengthen market settings that could encourage investment in EES.

5.1. Malaysia

Regulatory frameworks

Information gaps

Transparency and clarity for developers: EES developers need clear information regarding required capacities and available financing. Currently, with MyPOWER Corporation developing a new roadmap, the market structure is still developing, and limited guidelines for EES investments may impact investor confidence. Successfully introducing EES technology requires detailed capacity information, mainly guided by government regulations. Greater transparency and clarity in regulatory development would offer clearer signals and enhance investor confidence.

Economy-specific options

Enhance and clarify the EES regulatory framework: Since the widespread deployment of EES is a long-term goal, there is an opportunity to refine and clarify the EES regulatory framework to better incentivize investments. For instance, the government could establish specific timelines indicating future EES capacity requirements in each year to provide clear signals to the private sector.

Leverage existing hydro plants for PSH: To mitigate the high upfront cost of PSH development, Malaysia may consider using existing conventional hydro plants as one of the reservoirs. This could significantly lower the capital and operational costs associated with new PSH projects.

Economic case studies as signals to private sector: Conducting studies to analyze the economic and technical viability of EES projects would be beneficial. These studies will enable the government to signal the bankability of BESS projects in Malaysia to the private sector.

Financial support

Information gaps

Targeted incentives for EES: Financial incentives for energy storage systems are still limited. Tailored incentives for these types of projects would help reduce the high upfront costs and encourage investment in large-scale energy storage infrastructure.

Small-scale EES: There is an information gap on financing and incentives for small-scale or distributed energy storage systems, such as residential or commercial BESS. Support for these systems could enable more widespread adoption of EES technologies.

Economy-specific options

Provide targeted incentives for EES systems: Malaysia currently offers limited direct financial support for EES, despite the substantial costs associated with integrating these technologies. To foster EES adoption, it is crucial to develop a broader set of financial incentives that go beyond tax allowances. Options could include project-based subsidies, such as direct grants or rebates for battery storage in renewable energy projects, which would reduce initial costs for developers. Additionally, introducing performance-based incentives or credits for energy storage efficiency and capacity contributions could encourage a wider range of EES applications and attract private investment in standalone and integrated EES projects alike.

Market mechanisms

Information gaps

Structural limitations for investment in VRE projects: VRE projects may be unattractive for three reasons. First, electricity tariffs in some parts of Malaysia, such as Sabah, are heavily subsidized. Second, under the Gas Distribution Agreement, gas prices are discounted, making gas generation relatively cheap. Lastly, there is a low VRE penetration limit. These factors make the penetration of VRE, such as solar, and the adoption of EES less attractive.

Energy arbitrage opportunities: There is a lack of energy arbitrage opportunities for EES projects because the market prefers to provide energy through PPAs. While energy arbitrage can be conducted under NEDA, it has a limited capacity of 100 MW. This limited opportunity for arbitrage is a missed chance to provide signals to and encourage EES investors.

Ancillary service markets: Stakeholders in Malaysia recognized the need to further development of ancillary service market regulations and opportunities. While authorities including MyPOWER Corporation are working towards fine-tuning relevant guidelines, it is uncertain when they would be finalized which could pose a challenge to the private sector in deciding whether to invest in EES technologies or not.

Economy specific options

Expand and encourage NEDA: Further development and expansion of NEDA can provide more opportunities for energy arbitrage, making energy storage systems financially viable. Expanding the capacity beyond the current limit of 100 MW would offer more flexibility for investors in EES.

Allow competitive bidding for projects: Introducing competitive bidding processes for EES projects can enhance competitiveness and reduce costs. However, there should be policies in place to address the financial challenges related to the high costs of EES technologies, ensuring that these projects remain economically viable in the bidding process.

Increase VRE penetration limit: Raising the VRE penetration limit can make VRE and EES projects more attractive. Higher penetration of renewable energy would necessitate energy storage to balance the grid, thereby increasing demand for EES technologies. This can be achieved by reinforcing transmission infrastructure, such as developing interconnections between regions to improve flexibility in handling variable energy sources, or by deploying smart grid technologies that enable real-time monitoring and automation, enhancing grid stability and supporting higher levels of VRE integration.

Provide timeline for the development of ancillary market guidelines: Clear guidelines on ancillary services such as frequency regulation, voltage support, and reserve power would provide the private sector with the certainty needed to make informed investment decisions. Establishing a phased timeline for regulatory updates and involving private sector stakeholders in the regulatory process could enhance transparency and build investor confidence, encouraging greater participation in Malaysia's evolving EES market.

5.2. Papua New Guinea

Regulatory frameworks

Information gaps

Transparency and clarity for developers: The evolution of an energy policy framework in Papua New Guinea has been *ad hoc* (Department of Petroleum and Energy 2017). Several reviews have concluded that the policy and legislative frameworks for the energy sector have been characterized by lack of clarity and overlap in relation to intent and mechanisms for implementation (Department of Petroleum and Energy 2017). However, most of the recommendations of reviews have not been implemented, reflecting budgetary and human resource capacity constraints and inadequate political support (Asian Development Bank 2017). This contributes to policy uncertainty and can disincentivize private investors.

Policy awareness: There is a lack of policy awareness among stakeholders. For example, potential investors are generally unaware of the potential benefits of FIT schemes, making the development of these challenging in Papua New Guinea (Department of Petroleum and Energy 2017).

Capacity for grid-scale EES projects: There is little information on how Papua New Guinea intends to develop grid-scale energy storage projects to enhance grid stability. The economy could benefit from clearer guidelines and policies regarding the role of EES in grid modernization and how these systems can support renewable energy integration and grid resilience.

Economy-specific options

Incorporate EES in the National Electrification Strategy: The government could integrate energy storage as a key component of its

National Electrification Strategy. By incorporating EES into this strategy, a unified policy framework could emerge, promoting both grid-scale and off-grid energy storage solutions. For instance, the government could set specific targets for EES deployment, create supportive policies for storage integration in remote and underserved areas, and outline clear development plans to drive EES adoption. This approach would help ensure that energy storage technologies play a crucial role in achieving the economy's energy goals and enhancing energy reliability across all regions.

Financial support

Information gaps

Targeted incentives for EES: Currently, there are no specific incentives aimed at promoting EES development and investment. Substantial incentives or guarantees, such as insurance from the government or multilateral bodies, may be necessary to encourage private sector involvement in EES projects.

Affordability of off-grid EES: Affordability remains a significant barrier to the adoption of off-grid EES technologies, particularly in rural areas where households have low demand for SHS due to the high recurring costs of battery replacement.

Economy-specific options

Develop incentives for EES investment: The government could introduce specific incentives such as subsidies, grants, or tax exemptions for energy storage technologies. This would help reduce the financial risks associated with energy storage projects and make them more attractive to both domestic and foreign investors.

Introduce subsidies for off-grid battery systems: To improve energy access in remote and rural communities, the government could introduce targeted subsidies for off-grid battery systems. This would help alleviate the high upfront and recurring costs associated with battery replacement in SHS, for example, making energy storage more affordable for households and supporting the expansion of clean energy access.

Market mechanisms

Information gaps

PPA regulations: The regulatory framework surrounding the negotiation process of PPAs between the PPL and IPPs is still evolving. More transparent and consistent regulations are needed to provide certainty for IPPs and other private investors (Nepal et al 2023). Clear guidelines for PPA negotiations would create more confidence in the market, making it easier and more efficient for energy storage developers to plan projects.

Data collection for developing FIT: While Papua New Guinea is committed to developing a FIT schemes as an investment signal for RE projects, the economy faces the challenges of insufficient data and a lack of monitoring and analytical tool to determine the appropriate level of FIT remuneration for different technologies.

Economy-specific options

Establish mechanisms for long-term EES contracts: Creating clear mechanisms for long-term contracts that specifically target energy storage projects could provide much-needed certainty for investors. These mechanisms could be modelled on the existing PPAs for generation projects, but with a focus on storage technologies. Long-term contracts would offer a guaranteed revenue stream, encouraging more private sector participation in the EES market.

Explore competitive auctions for EES projects: Papua New Guinea could explore the use of competitive auctions to procure energy storage projects. This would promote competition, drive down costs, and allow the government to select the most efficient and cost-effective projects. Auctions for long-term contracts or capacity-based payments could ensure stable returns for investors, making the market more attractive for EES technologies.

5.3. Thailand

Regulatory frameworks

Information gaps

RE policies: In comparison to ASEAN member states, Thailand has fewer policies in place to stimulate the growth of RE (Yoo and Ha 2023). Some policies even discourage the use of RE by increasing the costs of using these technologies, relative to fossil fuels. For instance, PV projects incur license fees, adding to projects' operational expenditures. This can be an obstacle for the adoption of EES technologies.

Economy-specific options

Reduce or waive licensing fees for PV Projects: By eliminating or significantly reducing license fees on PV and other RE projects, Thailand can lower operational costs and improve the financial feasibility of renewable projects, creating a more favorable environment for integrating EES technologies.

Financial support

Information gaps

Targeted financial incentives for EES: There are few financial incentives that directly target energy storage systems, particularly for standalone EES technologies. Existing incentives, such as tax breaks and subsidies, are primarily aimed at the electric vehicle market or battery manufacturers, only indirectly benefiting energy storage. This may contribute to EES being seen as an unattractive investment (Yoon & Ha 2023).

Economy-specific options

Develop direct financial incentives for privately-owned EES: Thailand has opportunities to promote private sector investment in EES technologies by introducing financial incentives for both standalone systems and behind-the-meter EES. These incentives could include subsidies, grants, tax exemptions, and low-interest loans, which would reduce the financial barriers to EES development and increase private sector participation.

Market mechanisms

Information gaps

FIT: Under the Energy Regulatory Commission's Regulation for Procurement of Renewable Energy (2022-2030), the FIT system offers a limited procurement quota (100-200 MW per year). Given that a single solar-plus-storage project already has a maximum capacity of 90 MW, the annual quota restricts the number of projects that can be approved. This limited quota may not send a strong enough investment signal to attract large-scale private investment in EES technologies.

Need for clear investment signals: Despite Thailand's ambitions to increase renewable energy generation, there is a lack of clear, long-term investment signals specifically for EES technologies.

Investors require clear guidelines and incentives, such as long-term PPAs, FITs with larger quotas, and consistent policy frameworks to foster confidence in the EES market.

Economy-specific options

Develop energy arbitrage opportunities: Opportunities for privately-owned EES systems to engage in energy arbitrage remain limited. Providing energy arbitrage opportunities could encourage further investments in EES from the private sector. Thailand could, for instance, establish clear guidelines detailing eligible ancillary services for remuneration, along with transparent pricing structures. This clarity would give investors a reliable understanding of potential revenue streams, making EES investments more attractive. Additionally, Thailand could implement policies that allow EES systems to capitalize on peak and off-peak price differentials, creating a predictable and profitable environment for energy storage operators.

Provide effective investment signals by expanding the FIT quota: Thailand should aim to provide long-term investment signals to attract EES investors and achieve its energy security and sustainability goals. Expanding the FIT quota for ground-mounted solar projects plus battery storage, or broadening the FIT to include other EES technologies, would help ensure a stable revenue stream for investors. Clear investment signals will support greater private sector engagement and the expansion of the energy storage market.

Develop market monitoring mechanisms: With the anticipated growth of Thailand's electricity market, driven by greater participation from the private sector, there is a need for effective market monitoring mechanisms. Thailand should plan to strengthen grid management and monitoring tools to adapt to the changing market dynamics and ensure efficient operation, particularly as energy storage and renewable energy penetration increases.

6. Recommendations for APEC member economies

To meet APEC's renewable energy targets, member economies must fully commit to a clean energy transition, fundamentally reshaping the energy landscape. This shift will significantly impact the grid, requiring robust investments to upgrade electricity infrastructure and sustain supply-demand balance. EES will be a pivotal technology to support the renewable energy transition.

While many APEC economies expect EES projects to be government-led, scaling to a level that can accelerate renewable adoption will demand substantial capacity expansion, including calling for active private sector involvement. This is in fact the intent of many economies, including China; Thailand. Due to the large investment scales and potential risks associated with investments in EES, it will be important to create supportive market environments and effective policy frameworks to foster investment confidence and drive broader EES adoption.

Insights from the target economies of the projects — Malaysia; Papua New Guinea; Thailand — alongside the Australia; China; United States, underscore that advancing EES requires a multifaceted strategy. This includes implementing sound, context appropriate policies, as well as fostering supportive market mechanisms. At an individual economy scale, governments should examine ways that will ensure private investors can secure long-term profitability. Together, these steps build a strong foundation for an efficient and resilient clean energy transition across APEC.

This section draws on the effective market criteria outlined in Section 3 and insights from Australia; China; Malaysia; Papua New Guinea; Thailand; United States, to propose high-level recommendations for APEC member economies to strengthen their market settings for EES development and investment.

6.1. Regulatory frameworks

- **Targets and mandates:** Implement specific economy-wide and/or sub economy-wide targets for EES deployment. Consider utilizing mandates/incentives for EES integration with RE projects to enhance grid stability. For instance, Thailand incentivizes storage through a dual tariff rate for solar farms depending on whether or not they include BESS. Alternatively, a mandate could set minimum storage capacity requirements for all new solar and wind projects.
- **Policies for behind-the-meter applications**: This could include mandates or incentives related to the use of EES, such as BESS, with PV for commercial and industrial buildings.
- **Establish clear timelines for policy development**: Establish and publicize timelines for policy rollout to signal demand to the private sector, aiding in resource planning and investment readiness.
- **Enhance supportive policies for VRE projects**: Supportive policies for VRE projects such as gradually increasing the allowable percentage of VRE on the grid, creating a market need for supporting EES infrastructure, offering subsidies, grants and/or concessional finance for residential and utility scale VRE projects, and identifying renewable energy zones.
- **Create mechanisms for stakeholder engagement**: Develop regular, structured forums where stakeholders can submit questions and feedback on draft regulations, ensuring transparency and identifying policy gaps early. These mechanisms should also support stakeholder engagement in project planning and development stages.
- **Support for R&D**: Establish dedicated grants or tax credits for EES R&D projects, tailored to regional needs. For example, Australia’s Renewable

Energy Agency (ARENA) is a model of an agency that support R&D and innovation in clean energy.

6.2. Financial support

- **Government investments:** This could include governments covering all of the investment cost or establishing co-investment programs where government funds cover part of the project costs, with the remaining costs shared between international agencies and/or private investors.
- **Standalone system support**: Provide financial incentives like tax credits on standalone EES system costs, low-interest loans, or grant programs to reduce capital expenditure burdens for investors.
- **Behind-the-meter system incentives**: Offer subsidies that cover some installation costs for behind-the-meter EES systems (e.g., BESS with PV). Provide specific rebates for battery maintenance or replacement costs every 5–10 years.
- **Support for PSH**: Implement policies that cover a portion of the infrastructure development costs for PSH projects, such as tunnel construction subsidies or direct funding for necessary power station upgrades.
- **Financial incentives for RE projects**: Provide financial incentives for RE projects, which can act as indirect incentives for EES investments.

6.3. Market mechanisms

Where private sector is being used for EES development, the following market mechanism points should be considered in order to endure investor confidence:

- **Investment signals**: Implement long-term contracts like PPAs with specified minimum contract duration and fixed rate escalation clauses, with the aim of delivering revenue predictability and supporting investment stability.
- **Energy arbitrage**: Develop an energy arbitrage pricing model based on time-of-use rates to provide profit potential from price differentials. Encourage private EES operators to sell stored energy during peak demand periods
- **Competitive procurement**: Develop a competitive bidding process for EES projects with transparent criteria, such as a public auction system where bidders compete for government-backed EES projects, ensuring cost-effectiveness and fair competition.
- **Ancillary service markets**: Set up remuneration frameworks where EES projects earn payments for providing services such as frequency regulation, voltage control, and other grid-supportive services, with transparent and predictable pricing.
- **Capacity payments:** Implement capacity payment mechanisms that compensate EES providers for maintaining available storage capacity, ensuring grid reliability, and addressing peak demand.

6.4. Additional recommendations

- **Knowledge sharing**: Facilitate structured information exchanges between economies through workshops, trainings, or centralized digital platforms that share best practices, technical standards, and policy frameworks for EES.
- **Leveraging existing reservoirs for PSH development**: Develop policies that encourage the use of existing water reservoirs for PSH projects, as using established infrastructure can reduce capital costs as well as social and environmental impacts.
- **Conduct cost-benefit and feasibility studies**: Implement cost-benefit and feasibility assessments for proposed EES projects. This can provide a transparent scorecard highlighting financial, environmental and social factors.
- **Data collection and market monitoring**: Establish regular data collection protocols to track market demand, grid requirements, and storage utilization rates. This data can improve market transparency, enhance forecasting accuracy, and inform participants about opportunities.

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Annex A: Electrical Energy Storage

Background of Electrical Energy Storage (EES)

Many RE sources are highly variable due to their weather-dependent nature. The output of solar-based systems is dependent on sunlight which is affected by factors like time of day and cloud cover, while wind-based systems are affected by wind speed and variability. The output of these VRE sources cannot be adjusted to match energy demand. For example, the magnitude of PV output tends to peak at noon, when there is an abundance of sunlight. Such output can be higher than the demand for energy at that time. Without a mechanism for it to be stored, the excess energy is usually curtailed (i.e., thrown away) and wasted (Kan et. al. 2018, p. 47). High curtailment of solar PV is one of investors and rooftop solar owners' concerns, which is a potential obstacle to the development and widespread utilization of RE/VRE. For VRE to become a more dominant part of the global energy system, it is essential that there is a way to match energy supply with demand, such as through EES technologies.

EES refers to a process whereby electrical energy is generated at times when there is low demand, low cost and/or appropriate conditions for VRE generation, and is then converted to a form where it can be stored for conversion back to electricity when needed (Chen *et al*. 2009). Figure 9 demonstrates how EES works. Energy is supplied to a distribution network such as the grid. The EES system charges (i.e., stores) any excess energy (i.e., supply exceeds demand) that would have otherwise been curtailed. That stored energy can be discharged (i.e., fed back) into the distribution network to meet energy demands. EES facilitates grid flexibility by maintaining a balance between generation or supply and load or demand – effectively addressing the challenge of shifting to electricity generated by VRE. In general, as

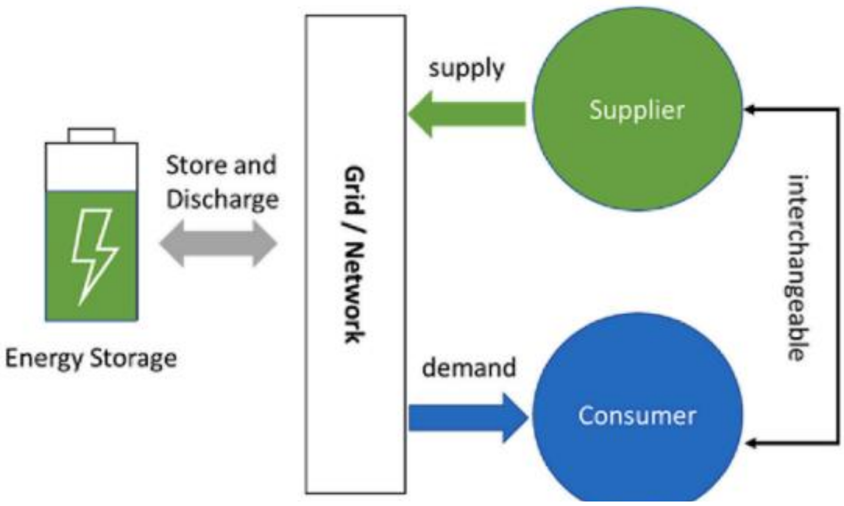


Figure 9: An interactive model between energy supply, demand and EES within a distribution network

the proportion of VRE generators in a grid increases, the requirement EES technologies increases as well (Gilfillan and Pittock 2022, p. 4).

Not only can EES provides a mechanism to reduce the curtailment rate of VRE, it also allows for greater efficiency of the energy market as consumers can buy the excess electricity during off-peak times when energy is cheap, and sell that stored electricity at a higher price during high-demand peak times.

Types of EES

There are a variety of technologies used for EES. Table 11 provides a list of main EES technologies as well as their descriptions.

Table 11: Description of the main EES technologies (Source: APEC 2022, p. 14)

EES Technology	Description
Pumped storage hydropower (PSH)	Water is pumped from a lower reservoir to a reservoir at higher elevation during off-peak periods. Subsequently, when energy is needed, the water is allowed to flow back down to the lower reservoir through a turbine and generate electricity in the process.
Flywheel energy storage	Flywheels are mechanical devices that spin at high speeds, storing electricity as rotational energy. The energy is released later by slowing down the flywheel's rotor, releasing quick bursts of energy (i.e. releases of high power and short duration).
Compressed air energy storage	Air is compressed and stored in underground caverns or storage tanks. The air is released later to a combustor in a gas turbine to generate electricity.
Chemical Batteries	Chemical reactions with two or more electrochemical cells enable the flow of electrons. These include lithium-based batteries (e.g. lithium-ion, lithium polymer), sodium sulphur, and lead-acid batteries.
Flow Batteries	Electricity is produced by dissolving two chemical components in an electrolyte separated by a membrane (e.g. vanadium redox flow battery).
Thermal Energy	Thermal energy is stored by heating or cooling a storage medium: Stored energy can be used later for heating or cooling applications or for power generation.

Figure 10 summarizes each EES technology based on its storage capacity and discharge time on power system applications. Storage capacity refers to the amount of energy that can be stored in an EES device or system. Discharge time refers to the amount of time it takes for that device or system to discharge completely. Storage capacity and discharge time are important in determining which EES technology to adopt.

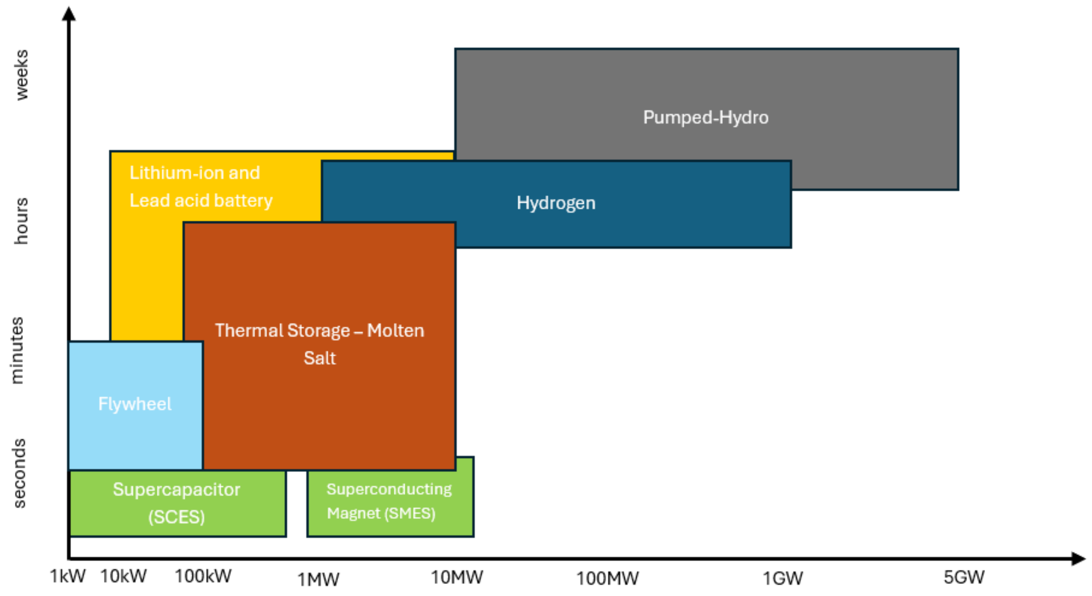


Figure 10: Representation of EES technologies based on its storage capacity and discharge time on power system application

Background of PSH

Among the various EES technologies, PSH stands out as the dominant technology that has been employed. In 2022, more than 95% of the world's energy storage capacity was PSH (Blakers and Nadolny 2023, p. 4). The technology is suited to longer periods of energy storage compared to batteries. PSH is an economically efficient and environmentally friendly technology for storing electrical energy for several reasons:

- **High efficiency**: PSH systems are highly efficient, with round-trip efficiency (i.e. the ratio between the energy supplied to an energy storage system and the energy retrieved from it) typically exceeding 70-80% (see Blakers et. al. 2021, p. 9; Javed et. al. 2020, p. 179).
- **Large storage capacity**: PSH has the largest storage capacity (see Figure 2). PSH systems can store between 1MW and 1GW worth of energy. This scalability makes them suitable for both local and grid-level applications.
- **Fast response time**: Response time refers to the time it takes for a storage system to provide energy at full rated power. The response time for PSH is within seconds to minutes (Javed et. al. 2020, p. 179). This means that PSH can respond quickly to changes in electricity demand or supply, making it suitable for providing grid stability and meeting peak demand in a timely manner.
- **Long lifecycle**: PSH facilities have a long operational lifespan compared to BESS which lasts between 8 and 15 years (ARENA 2017). PSH has around 50 years of life until refurbishment is needed. Well maintained PSH systems may be able to operate indefinitely. This makes PSH a reliable and long-term energy storage solution.

- **Low environmental costs**: PSH is a relatively clean and environmentally friendly technology, especially compared to conventional hydropower. It produces no direct emissions during operation and can help reduce the need for fossil fuel-based peaker plants, thereby contributing to GHG emissions reduction. Many PSH systems are designed to recycle and reuse water, minimizing the environmental impact on local ecosystems. Some systems use non-potable water sources, such as abandoned mines, for their reservoirs. PSH systems are also well suited to off-river locations, minimizing impacts on hydrology This also suggests that PSH has lower a social impact compared to conventional hydropower as people tend to inhabit in major river valleys (Gilfillan and Pittock 2022, p. 6).
- **Grid decentralization**: Distributed PSH facilities can be strategically located throughout a grid, reducing the need for long-distance transmission lines and increasing grid resilience against outages and extreme weather events.

While PSH has numerous advantages, it also faces challenges, including geographical constraints, high initial capital costs and the need for suitable topography and water sources (APEC 2022, p. 15). Nonetheless, it remains a critical component of how many economies have sought to use RE sources and enhance energy grid performance. As noted by Hydro wires (2020): “PSH facilities are often a least cost option for high capacity (both energy and power), long-duration storage, and can provide the flexibility and fast response that a high-VRE-penetration grid requires.”

Ancillary services

Table 11 provides the descriptions for some of the key ancillary services provided by EES systems.

Table 11: PSH’s available ancillary services

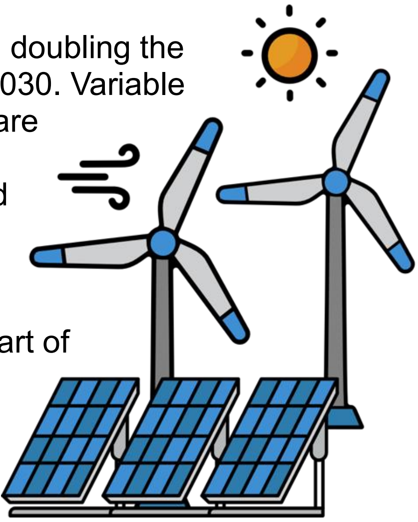
Service	Description
Spinning reserves	Rapidly respond to demand changes (e.g., when another generator goes offline without warning).
Frequency regulation	Stabilize the frequency of electricity in the grid.
Voltage support	Stabilize the voltage of electricity in the grid.
Black-start	Begin providing electricity when an entire electricity grid is blacked out.
	Fill a supply gap when VRE generators produce less than forecast.
Peak shaving	Store VRE produced electricity so it can be supplied to consumers at times of high demand.
Congestion relief	Alleviate grid congestion and enhance the overall efficiency and reliability of the electrical grid.
Power smoothing	Mitigate fluctuations in electrical power output.

Annex B: Policy Brief

POLICY BRIEF

Regulatory/Market Settings to Support Greater Electrical Energy Storage Development for Sustainable and Socially Responsible Electricity Sector CO2 Emissions Reductions in APEC Economies

Benefits of Electrical Energy Storage



In 2014, APEC member economies set an ambitious target: doubling the share of renewables in the energy mix between 2010 and 2030. Variable renewable energy (VRE) sources, such as solar and wind, are expected to see the largest growth in terms of capacity in APEC between 2020 and 2050. However, as solar and wind generators are inherently variable compared to traditional energy sources, achieving significant VRE integration will require substantial investments to modernize electricity infrastructure. Electrical energy storage (EES) is a critical part of the solution, capable of storing surplus VRE energy that might otherwise be wasted and supplying it when needed. This makes EES a pivotal technology to enhance grid flexibility and reliability and support the renewable energy transition in APEC.

The role of market settings

Market settings create the right conditions to help a market grow and function effectively. For EES, this means establishing rules, policies, and support systems that attract businesses and investors, enabling them to thrive. In many APEC economies, the EES market is currently still in its early stages of development, largely because most projects are government-driven, reducing the immediate demand for a broader market. To scale EES adoption to levels that support renewable energy goals, substantial growth in capacity is essential, requiring active private sector involvement. Achieving this will depend on creating a supportive market environment to strengthen EES markets and build investor confidence, especially as EES remains a costly and high-risk investment across many APEC economies.

Criteria of good market settings

Advancing EES requires a comprehensive and strategic approach. Insights from APEC member economies that have achieved notable progress in EES investments highlight three essential elements as criteria for good market settings to support greater EES development.

Regulatory frameworks Well-designed regulations provide the predictability and incentives needed to promote EES adoption and attract investment.

Financial support Financial support from the government can mitigate the high upfront capital costs of EES projects and incentivise private investment.

Market mechanisms Robust market mechanisms enhance the profitability of EES projects, bolstering investor confidence and ensuring project viability.

These three criteria serve as foundational pillars for guiding actionable recommendations and fostering an enabling environment for EES development.

Recommendations for APEC member economies

Building on the three criteria of good market settings, this section provides key recommendations to establish effective market conditions for EES technologies in APEC member economies. These recommendations aim to support a successful renewable energy transition across the region.

Regulatory frameworks

Targets and mandates: Implement specific domestic and/or sub-domestic targets for EES deployment. Consider utilizing mandates/incentives for EES integration with RE projects.

Policies for behind-the-meter applications: This could include mandates or incentives related to the use of EES, such as BESS, with PV for commercial and industrial buildings.

Establish clear timelines for policy development: Publicize clear timelines for policy rollout to signal demand and guide investment.

Enhance supportive policies for VRE projects: Gradually increase the allowable percentage of VRE on the grid, creating a market need for supporting EES infrastructure, offering subsidies, grants and/or concessional finance for residential and utility scale VRE projects, or identifying RE zones.

Create mechanisms for stakeholder engagement: Develop forums for stakeholder feedback on draft regulations and project planning

Support for R&D: Provide grants or tax credits for EES R&D projects, tailored to regional needs.

Financial support

Government investments: Fully fund or co-invest in EES projects with private/international partners.

Standalone system support: Offers tax credits, low-interest loans, or grants for standalone EES systems.

Behind-the-meter system incentives: Subsidize installation costs and offer battery maintenance/replacement rebates.

Support for PSH: Subsidize infrastructure development costs for PSH projects, such as tunnel construction or power station upgrades.

Financial incentives for RE projects: Provide financial incentives for RE projects to indirectly promote EES investments.

Market mechanisms

Investment signals: Use long-term contracts like PPAs with fixed rate escalation clauses for revenue stability.

Energy arbitrage: Enable energy arbitrage through time-of-use pricing models to boost profits.

Competitive procurement: Develop a transparent, competitive bidding process for EES projects.

Ancillary service markets: Compensate EES for providing ancillary services like frequency regulation and voltage control.

Capacity payments: Pay EES providers for maintaining available storage capacity to enhance grid reliability.

Additional recommendations

Knowledge sharing: Promote workshops, trainings, or centralized digital platforms that share best practices and standards.

Leveraging existing reservoirs for PSH development: Encourage the use of existing water reservoirs for PSH projects to reduce capital, social, and environmental costs.

Cost-benefit and feasibility studies: Conduct cost-benefit and feasibility studies for proposed EES projects.

Data collection and market monitoring: Regularly collect and share market data to improve market transparency and inform stakeholders.

Annex C: Report on the Malaysia Virtual Truthing Workshop

Introduction

Project Background

The APEC project, titled *Regulatory/Market Settings to Support Greater Electrical Energy Storage Development for Sustainable and Socially Responsible Electricity Sector CO2 Emissions Reductions in APEC Economies* (APEC Project EWG 03 2022A), aligns with the 2014 APEC statement on doubling aggregate share of renewables in the APEC energy mix by 2030. It does so by encouraging investment in electrical energy storage (EES) to ensure security of electricity supply in APEC economies. It also aligns with the 2011 APEC statement on energy resiliency, as EES allows electricity to continue to be distributed even when man-made or natural disasters damage generators.

The project examines existing market settings in 3 APEC economies that previously volunteered for the Peer Review on Low Carbon Energy Policies (PRLCE) project – Malaysia; Papua New Guinea (PNG); and Thailand. The purpose of this project is to determine market setting suitability in each economy for encouraging the use of pumped storage hydropower (PSH) and other EES technologies, in order to facilitate a transition to zero or low carbon electricity grids. Building on the PRLCE project, this project will develop economy specific options to fill EES market setting information gaps, as well as recommendations for adjustments to market settings for the purposes of encouraging investment in EES.

The project aims are being delivered through a combination of a Technical Report and workshops with relevant stakeholders in Malaysia; PNG; and Thailand. This report is focused on the Malaysia Virtual Truthing Workshop undertaken on 19 March 2024.

Workshop Purpose and Objectives

The primary objective of the Malaysia Virtual Truthing Workshop was to validate, extend, and revise the draft findings of the Technical Report with a particular focus on Malaysia.

The outcomes of the Malaysia focused workshop will inform the revision of the Technical Report. It will also inform the agenda for the Main Project workshop.

Activity Format

The Malaysia Virtual Truthing Workshop drew on a broad range of stakeholders from across government agencies and regulators, private entities, academia, and APEC member economies. Overall, 32 participants attended.

The Workshop agenda was designed to facilitate the dissemination of the draft Technical Report outputs from the project, allow for commentary and presentations from international experts and Malaysia government representatives, and facilitate the engagement and active participation of attendees towards achieving the primary objective of the Workshop. The Workshop Agenda is presented in Annex 1.

Workshop Conduct

Overall, the Workshop was considered a success by organizers and participants. The objective of validating, extending, and revising the draft Technical Report was achieved with useful inputs from stakeholders throughout the duration of the Workshop.

What worked

In relation to the objective to validate, revise, and extend the draft Technical Report, the Workshop was a qualified success. The Workshop was able to include with 32 stakeholders hear their insights on current EES and PSH projects, current market settings for EES and PSH, as well as policy and information gaps in Malaysia.

Throughout the Workshop, the design and facilitation were able to set the basis for an interactive environment to discuss the issues. Workshop attendees participated actively in both the small group breakout sessions as well as within the open Plenary. Engaging with stakeholders from different backgrounds proved beneficial in terms of refining the draft Technical Report's recommendations for good market settings in Malaysia. Facilitators within the breakout groups noted that stakeholders were actively involved in the discussions, including providing examples from their own sectors' experience. Participants reported that the views of stakeholders from different industrial and sectoral backgrounds are beneficial to move forward in EES/PSH implementation.

Limitations

Prior to the workshop, the Energy Working Group (EWG) focal point in Malaysia has noted that the virtual format of the workshop might be challenging to engage and hear from all participants. This view is shared by some workshop participants who said that online breakout groups were not as conducive to discussions as physical formats would be. Facilitators noted that, while discussions in the breakout groups were active, they were often led by only a few participants in the groups. Some participants did not appear to be present and did not engage in the discussions. This was a missed opportunity to receive feedback from all stakeholders to validate, extend, and refine the findings of the technical Report.

Evaluation feedback

At the end of the workshop attendees were requested to provide feedback on the suitability, interest, length, and topic selection of the workshop. Seven attendees filled the evaluation form (detailed at Annex 2) and the results are as follows.

The first section asked attendees to score several attributes of the workshop in a scale from 1 to 5 where 1 is strongly disagree and 5 is strongly agree. Table 1 shows the results for the main attributes.

Table 1 – Participant responses to the Workshop evaluation form (n = 7 responses)

	Evaluation question	Score (5)
1	The objectives of the workshops were clearly defined	4.43
2	The workshops achieved its intended objectives	4.00
3	The agenda items and topics covered were relevant	4.57
4	The content was well organized and easy to follow	4.71
5	Gender issues were sufficiently addressed during implementation	3.86
6	The speakers/experts were well prepared and knowledgeable about the topic	4.71
7	The materials distributed were useful	4.43
8	The time allotted for the training was sufficient.	4.57

The majority of the attributes were assessed to be very good, and good by the majority of attendees. The organization and pace of the workshop, and the quality of the presenters, in particular, were well received. The very strong results are very encouraging and demonstrate a strong appetite and need for further work in this area.

The form also asked the audience about the participants' knowledge of EES market settings prior to and after participating in the workshop, the relevance of the overall project to the participants' member economy, and additional comments. The majority of respondents (80%) indicated that they had very low to medium level of knowledge of EES market settings prior to the workshop. After the workshop, the majority of respondents (80%) indicated that they have medium to high level of knowledge. This highlighted the workshop's achievement in raising awareness about the benefits of EES and PSH, as well as beneficial market settings for EES technologies. Six out of seven respondents also indicated that the project was between "somewhat relevant" to "very relevant" to their economy, with four participants responding "very relevant" (one respondent abstained as this question was not mandatory).

The respondents were asked about the workshop's results and achievements. They commented positively about the workshop bringing together various stakeholders from different perspectives, and their granular views and inputs which are important to move forward with in EES implementation. They also praised the report which has relevant information on other economies.

Attendees were asked to provide areas for improvement. The only area of improvement the respondents identified was that the online format for group breakouts is not as conducive to fostering discussions as a physical format would be. This aligns with some of the comments made by member economies prior to the workshop that they would prefer the workshop to be in-person instead of virtual for more engaging participation.

Thinking of the future, the audience was asked about how they will apply the workshops' content and knowledge gained at your workplace. Responses included:

- Using the draft report and workshop presentations as a starting point to re-think market designing
- Develop strategies and work plan.

Next steps

The Malaysia Virtual Truthing Workshop serves as a useful learning opportunity for developing the PNG and Thailand Virtual Truthing Workshops and the Main Project Workshop. It is also an important stepping stone in progressing the development of the final Technical Report.

In terms of next steps, Sustineo is liaising with both Thailand's Ministry of Energy, and Papua New Guinea's National Energy Authority to confirm the dates of their Virtual Truthing Workshops. We are also working on the design of the Main Project Workshop with the 3 member economies.

Using the inputs from the Malaysia Virtual Truthing Workshop, Sustineo is working with stakeholders from Malaysia to revise the Malaysia Section of the draft Technical Report.

Workshop Agenda

Time	Activity	Lead
10:00-10:15	**Session 1: Workshop overview** Introduction of workshop and objectives.	Dr Ida Syahrina Bini Haji Shukor (Deputy Undersecretary, Energy Efficiency, Ministry of Energy Transition and Water Transformation) Mr Tom Sloan (CEO, Sustineo)
10:15-10:30	**Session 2: An introduction to EES and PSH** Overview on EES, and specifically PSH, from an international energy expert.	Dr Daniel Gilfillan (Independent Consultant)
10:30-10:45	**Session 3: Understanding energy planning and markets** Overview on different types of energy markets and planning, from an international energy expert.	Mr Martin Kennedy (Head of Sales (Hydropower, Australia, NZ and PNG), General Electrics)
10:45-11:00	**Session 4: Domestic presentation on current policy settings** Overview of Malaysia's current policy settings, EES plans, and renewable energy targets.	Mr Modh Erwan Isran (Deputy Undersecretary, Renewable Energy Section, Ministry of Energy Transition and Public Utilities)
11:00-11:15	**Session 5: Technical Report findings** Link to objectives: validate, extend, and revise the draft Technical Report. The presentation will provide a short overview of the key project findings, including current market settings for EES, policy or information gaps related to current	Ms Ngoc Trinh (Graduate Consultant, Sustineo)

	market settings for EES and draft economy-specific options to enhance good market settings for EES in Malaysia.	
11:15-11:45	**Session 6: Questions & Answers** This session will allow participants the chance to seek clarity or further information on the material presented.	Sustineo
11:45-12:15	**Break**	
12:15-13:00	**Session 7: Break-out sessions**. Workshop participants will break into x separate groups. The focus will be to discuss and interpret the research findings and recommendations, how they relate to and could build upon existing EES project activities in Malaysia and identify gaps. Discussions could also center around providing feedback and inputs on the draft options for changes that could be made to EES market settings in Malaysia.	Sustineo
13:00-13:45	**Session 8: Plenary session.** Each group will briefly present their comments. This will be followed by a plenary discussion of the key findings and recommendations, any key gaps, or considerations. We will also identify and gain agreement on actions for next steps.	Sustineo
13:45-13:55	**Summary**	
13:55-14:00	**Final Remarks**	Mr Tom Sloan (CEO, Sustineo)

Breakout question list

Discussion questions	Workshop Participant Responses
Validation	
Can you give some examples of completed, in-progress or planned EES projects in Malaysia?	
Are you aware of any enabling policies (including government targets, government direct investments, and financial incentives) for **EES** investments in Malaysia? Examples from the presentation: Domestic target of 500 Megawatts in EES capacity from 2030-2034 under the Peninsular Malaysia Generation Development Plan. The Green Investment Tax Allowance which gives foreign investors a 100% Investment Tax Allowance on Battery Energy Storage System installations.	
Besides the Net Offset Virtual Aggregation - Virtual Power Plants (NOVA-VPP), are you aware of any effective investment signals in Malaysia that incentivise investments in EES? Investment signals tell investors when to invest in/build EES facilities. Note that investment signals must satisfy two criteria. (1) Investment signals must **come early enough** given the long development lead time of some EES technologies such as pumped storage hydro which can take up to several years. (2) Investment signals should **last for a long time**. Due to the long development lead time and high operational costs, investors must be confident that once built, the EES system would be able to generate incomes for a long time.	
Are you aware of any ancillary services that EES can provide and be paid for in Malaysia? Currently, in Malaysia, we found that battery energy storage systems can provide services for spinning reserve, frequency regulation, voltage support and black start. The rates for these	

services are determined by Power Purchase Agreements.	
What are the information needs/gaps about the current EES market settings that that investors in Malaysia might face?	
Are there policy barriers to good market settings conducive to EES investments in Malaysia? Examples from the presentation: Lack of financial incentive such as subsidies or tax incentives for private developers/investors of EES technologies. Limited timespan of NOVA-VPP as an investment signal as it only allows consumers to engage in arbitrage for 10 years).	
What are the economy-specific options for changes that could be made to EES market settings in Malaysia to encourage additional EES investments? Examples from the presentation: The option to mandate the installation of Battery Energy Storage System with solar energy. Implement long-term investment signals.	
Considering that Pumped Storage Hydropower has a long lead time and is capital-intensive to develop and build, what level of support is needed to encourage investment?	

Annex D: Report on the Thailand Virtual Truthing Workshop

Introduction

Project Background

The APEC project, titled *Regulatory/Market Settings to Support Greater Electrical Energy Storage Development for Sustainable and Socially Responsible Electricity Sector CO2 Emissions Reductions in APEC Economies* (APEC Project EWG 03 2022A), aligns with the 2014 APEC statement on doubling aggregate share of renewables in the APEC energy mix by 2030. It does so by encouraging investment in electrical energy storage (EES) to ensure security of electricity supply in APEC economies. It also aligns with the 2011 APEC statement on energy resiliency, as EES allows electricity to continue to be distributed even when man-made or natural disasters damage generators.

The project examines existing market settings in 3 APEC economies that previously volunteered for the Peer Review on Low Carbon Energy Policies (PRLCE) project – Malaysia; Papua New Guinea (PNG); and Thailand. The purpose of this project is to determine market setting suitability in each economy for encouraging the use of pumped storage hydropower (PSH) and other EES technologies, in order to facilitate a transition to zero or low carbon electricity grids. Building on the PRLCE project, this project will develop economy specific options to fill EES market setting information gaps, as well as recommendations for adjustments to market settings for the purposes of encouraging investment in EES.

The project aims are being delivered through a combination of a Technical Report and workshops with relevant stakeholders in Malaysia; PNG; and Thailand. This report is focused on the Thailand Virtual Truthing Workshop undertaken on 23 May 2024.

Workshop Purpose and Objectives

The primary objective of the Thailand Virtual Truthing Workshop was to validate, extend, and revise the draft findings of the Technical Report with a particular focus on Thailand.

The outcomes of the Thailand focused workshop will inform the revision of the Technical Report. It will also inform the agenda for the Main Project workshop.

Activity Format

The Thailand Virtual Truthing Workshop drew on a broad range of stakeholders from across government agencies and regulators, private entities, academia, and APEC member economies. Overall, 26 participants attended.

The Workshop agenda was designed to facilitate the dissemination of the draft Technical Report outputs from the project, allow for commentary and presentations from international experts and Thailand government representatives, and facilitate the engagement and active participation of attendees towards achieving the primary objective of the Workshop. The Workshop Agenda is presented in Annex 1.

Workshop Conduct

Overall, the Workshop was considered a success by organizers and participants. The objective of validating, extending, and revising the draft Technical Report was achieved with useful inputs from stakeholders throughout the duration of the Workshop.

What worked

In relation to the objective to validate, revise, and extend the draft Technical Report, the Workshop was a qualified success. The Workshop was able to include with 26 stakeholders hear their insights on current EES and PSH projects, current market settings for EES and PSH, as well as policy and information gaps in Thailand.

The workshop's design and facilitation created an interactive environment for discussing issues. Attendees actively engaged in Q&A sessions with speakers and discussed the draft Technical Report, contributing to filling information gaps in the policy sector. Participants also reported that the discussions and presentations were beneficial for advancing EES/PSH implementation.

Limitations

Before the workshop, the Energy Working Group (EWG) focal point in Thailand expressed concerns about the challenges of engaging all participants in a virtual format. We indeed observed initial difficulties in facilitating discussion — although this issue was diminished as more participants spoke out. Ideally, smaller group discussions through breakout rooms would have been beneficial, but this structure was not approved by Thailand. This resulted in a missed opportunity to gather comprehensive feedback from all stakeholders to validate, extend, and refine the Technical Report findings.

Evaluation feedback

At the end of the workshop attendees were requested to provide feedback on the suitability, interest, length, and topic selection of the workshop. Six attendees filled the evaluation form (detailed at Annex 2) and the results are as follows.

The first section asked attendees to score several attributes of the workshop in a scale from 1 to 5 where 1 is strongly disagree and 5 is strongly agree. Table 1 shows the results for the main attributes.

Table 1 – Participant responses to the Workshop evaluation form (n = 6 responses)

	Evaluation question	Score (5)
1	The objectives of the workshops were clearly defined	4.67
2	The workshops achieved its intended objectives	4.67
3	The agenda items and topics covered were relevant	4.5
4	The content was well organized and easy to follow	4.67
5	Gender issues were sufficiently addressed during implementation	4.17
6	The speakers/experts were well prepared and knowledgeable about the topic	4.5
7	The materials distributed were useful	4.67
8	The time allotted for the training was sufficient.	4.33

The majority of the attributes were assessed to be very good, and good by the majority of attendees. The organization and pace of the workshop, and the relevance of the material before the workshop, in particular, were well received.

The form also asked the audience about the participants' knowledge of EES market settings prior to and after participating in the workshop, the relevance of the overall project to the participants' member economy, and additional comments. Most respondents indicated an increase in understanding after the workshop compared to before. This highlighted the workshop's achievement in raising awareness about the benefits of EES and PSH, as well as beneficial market settings for EES technologies. All respondents also indicated that the project was between "very relevant" and "mostly relevant" to their economy.

Looking ahead, the audience was asked how they plan to apply the knowledge and content gained from the workshops in their workplaces. Responses included using the information to enhance and develop policies.

Next steps

The Thailand Virtual Truthing Workshop serves as a useful learning opportunity for developing the Main Project Workshop. It is also an important stepping stone in progressing the development of the final Technical Report.

Using the inputs from the Thailand Virtual Truthing Workshop, Sustineo is revising the Thailand Section of the draft Technical Report.

Workshop Agenda

Time	Activity	Lead
10:00-10:10	**Session 1: Workshop overview** Introduction of workshop and objectives.	Sustineo Mr Woranon Chansiri (Executive Director of International Affairs Division, Office Of Permanent Secretary, Ministry of Energy)
10:10-10:20	**Session 2: An introduction to EES and PSH** Overview on EES, and specifically PSH, from an international energy expert.	Dr Daniel Gilfillan (Daniel Gilfillan Consulting)
10:20-10:35	**Session 3: Understanding energy planning, and markets** Overview on different types of energy markets and planning, from an international energy expert.	Mr Martin Kennedy (GE)
10:35-10:55	**Session 4: Questions & Answers with international energy experts** This session will allow participants the chance to seek clarity or further information on the material presented by the international energy expert.	Sustineo
10:55-11:05	**Session 5: Domestic presentation on current policy settings** Overview of Thailand's current policy settings, EES plans, and renewable energy targets.	Mr Surasit Tanthadiloke (Plan and Policy Analyst, Energy Policy and Planning Office)
11:05-11:25	**Session 6: Technical Report findings** The presentation will provide a short overview of the key project findings, including current market settings for EES, policy or information gaps related to current	Sustineo

	market settings for EES and draft economy-specific options to enhance good market settings for EES in Thailand.	
11:25-11:55	**Session 7: Questions, Answers & Comments with Thailand's stakeholders regarding the Technical Report findings** This session will allow participants to validate, correct or clarify information on the material presented from the Technical Report findings presentation.	Sustineo
11:55-12:05	**Break**	
12:05-12:20	**Session 7: Extension discussion – further validation of the Technical Report with Thailand stakeholders (Optional)** This session will further validate research findings and recommendations, with a particular focus on building upon existing EES project activities in Thailand, and identify gaps. Beyond providing key actions to address in improvement the Technical Report and next steps for the overall project, this will also provide an opportunity for further Q&A with the international expert speakers.	Sustineo
12:20-12:30	**Final Remarks**	Sustineo
12:30-14:00	**Zoom meeting open for anyone wanting to stay and ask questions**	Sustineo

Annex E: Report on the Papua New Guinea Virtual Truthing Workshop

Introduction

Project Background

The APEC project, titled *Regulatory/Market Settings to Support Greater Electrical Energy Storage Development for Sustainable and Socially Responsible Electricity Sector CO2 Emissions Reductions in APEC Economies* (APEC Project EWG 03 2022A), aligns with the 2014 APEC statement on doubling aggregate share of renewables in the APEC energy mix by 2030. It does so by encouraging investment in electrical energy storage (EES) to ensure security of electricity supply in APEC economies. It also aligns with the 2011 APEC statement on energy resiliency, as EES allows electricity to continue to be distributed even when man-made or natural disasters damage generators.

The project examines existing market settings in 3 APEC economies that previously volunteered for the Peer Review on Low Carbon Energy Policies (PRLCE) project – Malaysia; Papua New Guinea; and Thailand. The purpose of this project is to determine market setting suitability in each economy for encouraging the use of pumped storage hydropower (PSH) and other EES technologies, in order to facilitate a transition to zero or low carbon electricity grids. Building on the PRLCE project, this project will develop economy specific options to fill EES market setting information gaps, as well as recommendations for adjustments to market settings for the purposes of encouraging investment in EES.

The project aims are being delivered through a combination of a Technical Report and workshops with relevant stakeholders in Malaysia; PNG; and Thailand. This report is focused on the Papua New Guinea Virtual Truthing Workshop undertaken on 27 August 2024.

Workshop Purpose and Objectives

The primary objective of the Papua New Guinea Virtual Truthing Workshop was to validate, extend, and revise the draft findings of the Technical Report with a particular focus on Papua New Guinea.

The outcomes of the Papua New Guinea focused workshop will inform the revision of the Technical Report. It will also inform the agenda for the Main Project workshop.

Activity Format

The Papua New Guinea Virtual Truthing Workshop drew on a broad range of stakeholders from across government agencies and regulators, private entities, academia, and APEC member economies. Overall, 20 participants attended.

The Workshop agenda was designed to facilitate the dissemination of the draft Technical Report outputs from the project, allow for commentary and presentations from international experts and Papua New Guinea government representatives, and facilitate the engagement and active participation of attendees towards achieving the primary objective of the Workshop. The Workshop Agenda is presented in Annex 1.

Workshop Conduct

Overall, the Workshop was considered a success by organizers and participants. The objective of validating, extending, and revising the draft Technical Report was achieved with useful input from stakeholders throughout the Workshop.

What worked

In relation to the objective to validate, revise, and extend the draft Technical Report, the Workshop was a qualified success. The Workshop was able to engage with 20 stakeholders hear their insights on current EES and PSH projects, current market settings for EES and PSH, as well as policy and information gaps in Papua New Guinea.

The design and facilitation of the Workshop successfully established an interactive environment conducive to discussing key issues. The presence of a Sustineo consultant in Port Moresby to facilitate breakout discussions enhanced the level of engagement during the Workshop. Attendees actively participated in both the small group breakout sessions and the open Plenary.

Participants noted that the materials presented in the Workshop, including the presentations and draft Technical Report, were valuable for understanding EES/PSH implementation.

Limitations

The agenda was heavily focused on presentations, which posed challenges for engaging participants. Facilitators observed that while discussions in the breakout groups were active, they were often dominated by a few participants, with some attendees not actively engaging in the discussions. This represented a missed opportunity to gather feedback from all stakeholders, which could have been used to validate, expand, and refine the findings of the draft Technical Report. The online format was noted as contributing to these difficulties.

Having perspectives from a broader range of stakeholders, including more from the private sector would have been valuable. However, the lead-up to the workshop coincided with a busy period for Papua New Guinea. This mean that invitations sent by the National Energy Authority (NEA) were delayed in being delivered.

Evaluation feedback

At the end of the workshop attendees were requested to provide feedback on the suitability, interest, length, and topic selection of the workshop. Three attendees filled the evaluation form (detailed at Annex 2) and the results are as follows.

The first section asked attendees to score several attributes of the workshop in a scale from 1 to 5 where 1 is strongly disagree and 5 is strongly agree. Table 1 shows the results for the main attributes.

Table 1 – Participant responses to the Workshop evaluation form (n = 3 responses)

	Evaluation question	Score (5)
1	The objectives of the workshops were clearly defined	4
2	The workshops achieved its intended objectives	4.3
3	The agenda items and topics covered were relevant	4.7
4	The content was well organized and easy to follow	4
5	Gender issues were sufficiently addressed during implementation	4
6	The speakers/experts were well prepared and knowledgeable about the topic	4.7
7	The materials distributed were useful	4.3
8	The time allotted for the training was sufficient.	4

Although the number of responses was lower than anticipated due to other commitments of stakeholders from the NEA, the feedback received was very positive. The agenda items and topics covered were considered highly relevant, and the quality of the presenters was particularly well received.

The respondents were asked to elaborate on the relevance of the Workshop to them and their economy, all of them indicated that the project is between “Mostly relevant” and “Very relevant”. Participants from Papua New Guinea noted that the Project is “relevant to the current developments of photovoltaic and battery energy storage system guidelines.” In response to the question, "How will you apply the Workshop's content and knowledge gained at your workplace?", stakeholders indicated that it would aid in developing new policy initiatives, regulations, procedures, and training programs. These responses align with the Workshop discussions on Papua New Guinea’s efforts towards regulating renewable energy and EES. They underscore the project’s role in raising awareness about the benefits of EES and PSH, as well as the importance of supportive market settings for EES technologies.

The respondents were asked about the workshop’s results and achievements. They commented positively about the findings in the draft Technical Report, and the Workshop’s achievement in providing a bigger picture of Papua New Guinea’s energy regulatory framework and market settings to support EES. Stakeholders noted that they have more understanding and knowledge about PSH. This is a positive outcome since PSH is still a nascent technology in Papua New Guinea.

Attendees were asked to suggest areas for improvement, and respondents highlighted the need for information on Papua New Guinea's electricity context and its pivotal role in the economy's energy sector. This feedback is fair and constructive. Although the agenda initially included a 15-minute presentation from a representative of the NEA on Papua New Guinea's electricity market, the presenter was unable to attend due to unforeseen circumstances.

Thinking of the future, the audience was asked about what needs to be done next by APEC. Only one response was provided for this, suggesting greater collective actions by fora.

Next steps

The Papua New Guinea Virtual Truthing Workshop serves as a useful learning opportunity for developing Main Project Workshop. It is also an important steppingstone in progressing the development of the final Technical Report.

In terms of next steps, Sustineo is liaising with member economies and international experts in preparing for the Main Project Workshop in October.

Using the inputs from the Papua New Guinea Virtual Truthing Workshop, Sustineo is working with stakeholders from Papua New Guinea to revise the Papua New Guinea Section of the draft Technical Report.

Workshop Agenda

Time	Activity	Lead
1:30-1:45	**Session 1: Workshop overview** Introduction of workshop and objectives.	Sustineo
1:45-2:00	**Session 2: An introduction to EES and PSH** Overview on EES, and specifically PSH, from an international energy expert.	Dr Daniel Gilfillan
2:00-2:15	**Session 3: Understanding energy planning and markets** Overview on different types of energy markets and planning, from an international energy expert.	Mr Martin Kennedy
2:15-2:30	**Session 4: Domestic presentation by People's Republic of China** Topic: China's policy mechanisms for the development of new energy storage and grid dispatching	Dr Wang Libing (Huadian Group)
2:30-2:45	**Session 6: Questions & Answers with international experts** This session will allow participants the chance to seek clarity or further information on the material presented.	Sustineo
2:45-3:15	**Break**	
3:15-3:30	**Session 7: Technical Report findings** *Link to objectives: validate, extend, and revise the draft Technical Report.* The presentation will provide a short overview of the key project findings, including current market settings for EES, policy or information gaps related to current market settings for EES and draft economy-specific options to enhance good market settings for EES in Papua New Guinea.	Sustineo
3:30-4:15	**Session 8: Break-out session.** Workshop participants will break into separate groups. The focus will be to discuss and interpret the research findings and recommendations, how they relate to and could build upon existing EES project activities in Papua New Guinea and identify gaps. Discussions could also center around providing feedback and inputs on the draft options for changes that could be made to EES market settings in Papua New Guinea.	Sustineo
4:15-4:45	**Session 9: Plenary session.** Each group will briefly present their comments. This will be followed by a plenary discussion of the key findings and recommendations, any key gaps, or considerations. We will also identify and gain agreement on actions for next steps.	Sustineo
4:45-4:55	**Summary**	
4:55-5:00	**Final Remarks**	Sustineo

Breakout question list

Discussion questions	Workshop Participant Responses
Validation	
Can you give some examples of completed, in-progress or planned EES projects in Papua New Guinea? How are they funded? Examples from the presentation: • **National Energy Access Transformation Project** • 9MW Solar + 2 Hr Battery Storage in Markham • PNG Biomass' projects under Power Purchase Agreements with PPL • **Gelion–Mayur Renewables clean energy projects**	
Are you aware of any enabling policies (including government targets, government direct investments, and financial incentives) for **EES** investments in Papua New Guinea? Guiding questions: According to the National Electricity Roll-Out Plan, communities are to be electrified by either the extension of PPL's existing grids, isolated grids that may include several generation sources, or solar PV systems used for small settlements. Isolated grids using hybrid generation systems of PV panels **may require storage batteries**. Is there any mandate or regulation on the use of storage batteries for these generation systems?	
How are EES projects in Papua New Guinea financed or remunerated? Guiding questions: • What proportion of EES projects in Papua New Guinea is expected to be owned and funded by the government? How about the private sector? • Are EES projects eligible for any Feed-in-Tariff scheme, such as the Renewable Energy Policy outlined in the National Energy Policy 2017-2027? • Do Power Purchase Agreements between PPL and independence power producers include EES projects? If yes,	

are these agreements effective in promoting private investment in EES? • Have Public-Private Partnership agreements been effective in promoting private investment in EES?	
Are you aware of any effective investment signals in Papua New Guinea that incentivise investments in EES? Investment signals tell investors when to invest in/build EES facilities. Note that investment signals must satisfy two criteria. (1) Investment signals must **come early enough** given the long development lead time of some EES technologies such as pumped storage hydro which can take up to several years. (2) Investment signals should **last for a long time**. Due to the long development lead time and high operational costs, investors must be confident that once built, the EES system would be able to generate incomes for a long time.	
Are you aware of any ancillary services that EES can provide and be paid for in Papua New Guinea? Example of ancillary services: frequency/voltage control, ready to dispatch capacity payments. If these services are renumerated, who would pay?	
Extension	
What are the information needs/gaps about the current EES market settings that that investors in Papua New Guinea might face?	
Are there policy barriers to good market settings conducive to EES investments in Papua New Guinea? Examples from the presentation: Lack of clear regulation around EES which can creates uncertainty for and disincentivise private investors. Lack of financial incentive such as subsidies or tax incentives for private developers/investors of EES technologies, also for off-grid EES such as batteries in solar home systems.	
What are the economy-specific options for changes that could be made to EES market settings in Papua New Guinea to encourage additional EES investments?	

Examples from the presentation: EES targets or mandates. More transparent regulations around the negotiation of Power Purchase Agreements between PPL and independent power producers. Transparency gives these producers certainty. Auctioning of long-term contracts with the private sector to promote competition.	
Considering that Pumped Storage Hydropower has a long lead time and is capital-intensive to develop and build, what level of support is needed to encourage investment?	

Annex F: Report on the Main Project Workshop

Introduction

Project Background

The APEC project, titled *Regulatory/Market Settings to Support Greater Electrical Energy Storage Development for Sustainable and Socially Responsible Electricity Sector CO2 Emissions Reductions in APEC Economies* (APEC Project EWG 03 2022A), aligns with the 2014 APEC statement on doubling aggregate share of renewables in the APEC energy mix by 2030. It does so by encouraging investment in electrical energy storage (EES) to ensure security of electricity supply in APEC economies. It also aligns with the 2011 APEC statement on energy resiliency, as EES allows electricity to continue to be distributed even when man-made or natural disasters damage generators.

The project examines existing market settings in 3 APEC economies that previously volunteered for the Peer Review on Low Carbon Energy Policies (PRLCE) project –Malaysia; Papua New Guinea (PNG); and Thailand. The purpose of this project is to determine market setting suitability in each economy for encouraging the use of pumped storage hydropower (PSH) and other EES technologies, in order to facilitate a transition to zero or low carbon electricity grids. Building on the PRLCE project, this project will develop economy specific options to fill EES market setting information gaps, as well as recommendations for adjustments to market settings for the purposes of encouraging investment in EES.

The project aims are being delivered through a combination of a Technical Report and workshops with relevant stakeholders in Malaysia; PNG; and Thailand. This report is focused on the Main Project Workshop on 15 and 16 October 2024.

Workshop Purpose and Objectives

The primary objective of the Main Project Workshop was to further validate and extend the key findings presented in the Technical Report, particularly as they pertain to different economies across the APEC region. The workshop was designed to both strengthen the Technical Report and identify lessons and opportunities for the APEC region to be presented in the APEC Policy Brief.

Participants of the Main Project Workshop were energy experts from APEC member economies, including from government, industry, research and other non-government sectors.

Activity Format

The Main Project Workshop drew on a broad range of stakeholders. Overall, 36 participants attended across the two workshop days (15 and 16 October 2024).

The Workshop agenda was designed to facilitate the dissemination of the draft Technical Report outputs from the project, allow for commentary and presentations from international experts and member economies' energy working groups, and facilitate the engagement and active participation of attendees towards achieving the primary objective of the Workshop. The Workshop Agenda is presented in Annex 1.

Workshop Conduct

Overall, the Workshop was considered a success by organizers and participants. The objective of validating, extending, and revising the draft Technical Report was achieved with useful inputs from stakeholders throughout the duration of the Workshop.

What worked

The Workshop aimed to validate, revise, and expand the draft Technical Report, and it was largely successful in meeting these objectives. Over the course of two days, participants from Australia, Malaysia, PNG, Thailand and other member economies provided insights on ongoing EES and PSH projects, market conditions for these sectors, and policy and information gaps within their economies.

The Workshop's design and facilitation fostered an interactive environment for discussing these topics. On Day One (15 October 2024), international experts in EES and PSH presented on relevant issues. These sessions, which included Q&A and a panel discussion on EES technologies, provided opportunities for APEC member economies to explore potential expansion. Attendees actively participated, asking questions pertinent to their own contexts, which facilitated knowledge sharing as intended.

Day Two (16 October) focused on market settings conducive to EES investment. Attendees engaged in breakout sessions and open plenary discussions, which enabled cross-learning among participants from various member economies and sectors. Insights from these discussions contributed not only to refining the draft Technical Report but also to shaping the upcoming APEC Policy Brief.

Limitations

The virtual format of the workshop presented organizational challenges, particularly in coordinating a time that suited participants from different member economies. With the workshop spanning 8 hours over two days, maintaining engagement in a virtual setting proved challenging, a sentiment shared by some participants. Despite these challenges, the workshop was still successful in engaging stakeholders, particularly during the interactive breakout sessions.

Evaluation feedback

At the end of the workshop attendees were requested to provide feedback on the suitability, interest, length, and topic selection of the workshop. Three attendees filled the evaluation form[4] (detailed at Annex 2) and the results are as follows.

The first section asked attendees to score several attributes of the workshop in a scale from 1 to 5 where 1 is strongly disagree and 5 is strongly agree. Table 1 shows the results for the main attributes.

Table 1 – Participant responses to the Workshop evaluation form (n = 3 responses)

	Evaluation question	Score (out of 5)
1	The objectives of the workshops were clearly defined	4.33
2	The workshops achieved its intended objectives	4.00
3	The agenda items and topics covered were relevant	4.67
4	The content was well organized and easy to follow	4.33
5	Gender issues were sufficiently addressed during implementation	4.67
6	The speakers/experts were well prepared and knowledgeable about the topic	4.67
7	The materials distributed were useful	4.67
8	The time allotted for the training was sufficient.	4.67

Most workshop attributes were rated as "very good" or "good" by attendees, with the speaker's expertise and quality of distributed materials receiving particularly positive feedback. These strong results indicate a clear interest and need for continued work in this area.

The evaluation form asked participants about their knowledge of EES market settings before and after the workshop, the relevance of the project to their economy, and for additional feedback. Two out of three respondents indicated a medium level of prior knowledge, which increased to medium-to-high after the workshop, underscoring the event's success in raising awareness about EES and PSH benefits and effective market settings for EES technologies. All respondents rated the project as "mostly relevant" to "very relevant" for their economy, with comments emphasizing its timeliness for the renewable energy transition. A participant from PNG noted that it could improve reliability in PNG's electricity

[4] Four responses were submitted for the feedback survey. However, one response was completed in just one minute, while the average time to complete the survey was 15 minutes. This particular response showed irregular patterns, with "Strongly Disagree" selected for all options without any accompanying comments or explanations, raising concerns about its reliability. We recommend excluding this response due to its questionable validity. If it is included, the average scores across the eight questions are as follows: 3.5, 3.3, 3.8, 3.5, 3.8, 3.8, 3.8, and 3.8.

sector, while another participant highlighted the importance of recognizing the bankability of large-scale PSH projects in the region.

When asked about the workshop's achievements, respondents commended the opportunity for cross-sector stakeholder engagement, which fostered valuable knowledge sharing on EES and market conditions. Attendees also noted that the workshop was well-organized.

Suggestions for improvement included holding future sessions offline for greater impact and featuring more insights from Australia's experience.

Thinking of the future, the audience was asked about what could be done next by APEC. Responses included:

- APEC to revise its target for the renewable energy transition
- Forming a platform to facilitate exchanges among member economies
- Provide trainings for member economies such as Papua New Guinea in adopting EES

Next steps

Based on the insights gathered from the Main Project Workshop and the Virtual Truthing Workshops held with Malaysia; PNG; and Thailand, Sustineo is revising the Technical Report and is also working on the Policy Brief. The next step is to send the revised Technical Report to APEC Secretariate for member economy considerations soon.

Workshop Agenda

Day One: 15 October 2024

Time (AEDT)	Activity	Lead
13:00–13:15	**Session 1: Workshop overview** Introduction of workshop and objectives.	APEC Energy Working Group Representatives Sustineo
13:15–13:35	**Session 2: An introduction to EES and PSH in the APEC context**	Dr Daniel Gilfillan
13:35–13:55	**Session 3: PSH's contribution to APEC's economic development and clean energy transition**	Rebecca Ellis (International Hydropower Associations)
13:55–14:15	**Session 4: Review of existing opportunities for expanding PSH in APEC member economies**	Professor Andrew Blakers (The Australian National University)
14:15–15:00	**Session 5: Moderated Questions & Answers** This session will allow participants the chance to seek clarity or further information on the material presented.	Sustineo
15:00–15:30	**Break**	
15:30–16:00	**Session 6: Presentation from Papua New Guinea** Overview of current policy landscape and direction of the energy sector in Papua New Guinea	Mr Christopher Gola National Energy Authority (Papua New Guinea)
16:00–16:45	**Session 8: Panel discussion — Common opportunities, challenges and lessons.** Discussion will focus on participant reflections on presentations with international experts (Session 2-4) and member economies (Session 7), particularly in sharing lessons, opportunities and challenges from EES and PSH in the APEC context.	Moderator: Dr Daniel Gilfillan Panellists: Professor Jamie Pittock, Ms Rebecca Ellis, and Mr Martin Kennedy.
16:45–17:00	**Summary and closing remarks for Day One**	Sustineo

Day Two: 16 October 2024

Time (AEDT)	Activity	Lead
13:00–13:15	**Session 1: Workshop overview and recap** Recap of the workshop objectives and a brief recap, presenting a synthesis of common lessons identified from Day 1.	APEC Energy Working Group Representatives Sustineo
13:15–13:30	**Session 2: Overview of the importance of market settings for EES/PSH**	Mr Martin Kennedy
13:30–13:45	**Session 3: Presentation from Thailand's Energy Working Group** Overview of current and planned policy settings to promote EES investments in Thailand	Ministry of Energy (Thailand)
13:45–14:15	**Session 5: Questions & Answers** This session will allow participants the chance to seek clarity or further information on the material presented.	Sustineo
14:15–14:45	**Break**	
14:45–15:00	**Session 6: Options for promoting market settings that will enable promotion of EES and PSH for APEC member economies** The presentation will provide a short overview of the draft economy-specific options to enhance good market settings for EES in APEC member economies. It will present recommendations on options member economies could take to promoting EES and PSH.	Sustineo
15:00–15:45	**Session 7: Discussion/break-out sessions**. Workshop participants will break into smaller groups. Discussions would centre around proposed options to promoting EES and PSH in context of APEC member economies.	Sustineo
15:45–16:15	**Session 8: Plenary session.** Each group will briefly present their comments. This will be followed by a plenary discussion of the key findings and recommendations, any key gaps, or considerations. We will also identify and gain agreement on actions for next steps.	Sustineo
16:15–16:25	**Summary**	
16:25–16:30	**Final Remarks**	Sustineo

Breakout question list

Discussion questions	Workshop Participant Responses
Understanding your economy's experience	
Please give a short overview of Electrical Energy Storage (EES) and Pumped Storage Hydropower (PSH) in your economy. What has been the experience of your member economy with adopting EES? Is the technology still emerging, or is it already widely used? What are some policies to support EES investment in your economies (e.g., government targets, direct investment or financial incentives)?	
Opportunities to enhance market-settings to encourage EES investment	
What do you see as the main factor driving investment in Energy Storage Systems (EES) in your economy or in general? Some possible examples include: Clear and transparent regulations for EES, such as specific targets or mandates for EES installation Financial support, such as government funding, co-investment, or subsidies Opportunities to generate revenue through market mechanisms, including power purchase agreements, energy arbitrage (storing energy when prices are low and selling when they are high), and payments for providing ancillary services like frequency regulation or black start capabilities.	
Are there policy-related barriers to EES investment in your economy? Examples: Unclear regulations, which create uncertainty and discourage private investment A lack of financial incentives, such as subsidies or tax incentives, for private EES developers or investors Limited market opportunities for private investors to earn revenue from EES.	
In your opinion, what is the most important first step to promote EES investment and adoption in your economy? What changes could be made to EES policies to attract more investment?	

Is there anything else you would like to add to the criteria of good market settings to encourage EES investment? Here are the criteria we have presented: Regulatory framework: Clear, transparent policies with tailored regulations for different EES technologies, allow stakeholders to engage and ask questions about regulatory changes Financial support: Government funding, co-investment, or subsidies to encourage private investment Market opportunities: Revenue streams for EES investors, such as power purchase agreements, energy arbitrage, and payments for ancillary services like frequency regulation and black start capabilities	
Considering that Pumped Storage Hydropower has a long development timeline and is expensive to build, what level of support is needed to encourage investment?	