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APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply

APEC Energy Working Group

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TECHNICAL PAPER

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ABBREVIATIONS

ANU	Australian National University
APEC	Asia Pacific Economic Community
ARENA	Australian Renewable Energy Agency
ASEAN	Association of South East Asian Nations
CIS	Commonwealth of Independent States (A grouping of Russian aligned states)
EMA	Energy Management Authority (Singapore)
ESS	Energy Storage Systems (e.g. batteries, pumped storage hydropower)
EVN	Viet Nam Electricity
EVN	Viet Nam Electricity
FTM	Front of the Meter (used to refer to storage on the electricity supplier side of the electricity meter)
GMS	Greater Mekong Subregion
GW	Giga Watt (10^9 Watts)
GWh	Giga Watt hours (1GWh is equal to a power supply of 1GW for one hour)
HAPUA	Heads of ASEAN Power Utilities/Authorities
HARP	Hydrogen Assisted Renewable Power
HK	Hong Kong
HK$	Hong Kong Dollar
HKD	Hong Kong Dollars
HVDC	High Voltage Direct Current (an electricity transmission method)
ICEM	International Centre for Environmental Management
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
Lao PDR	Lao Peoples Democratic Republic
Lao PDR	Lao Peoples Democratic Republic
MRC	Mekong River Commission
MW	Mega Watt (10^6 Watts)
MWh	Mega Watt hours (1MWh is equal to a power supply of 1MW for one hour)
NDC	Nationally Determined Contribution (related to the Paris Agreement)
NEM	National Electricity Market (Australia)
PHES	Pumped Hydro-electric Storage (another term for PSH)
PHP	Philippines Peso
PJSC	Public Joint Stock Company (Russia)
PLN	Perusahaan Listrik Negara (Indonesia’s dominant state power company)
ROK	Republic of Korea

PSH	Pumped Storage Hydropower
PV	Photo Voltaic
RE	Renewable Energy
RPS	Renewable Portfolio Standard (a mechanism for encouraging growth in renewable energy generation)
SD$	Singapore Dollars
SEA	Chile’s Aysén Electric System
SEDA	Malaysia’s Sustainable Energy Development Authority
SEM	Chile’s Magallanes Electric System
SEN	Chile’s National Electric System
TES	Thermal Energy Storage
TPES	Total Primary Energy Supply
UNFCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
UTS	University of Technology Sydney
VRE	Variable Renewable Energy (in contrast with hydropower, which is sometimes classed as a renewable energy source)
WWF	World Wide Fund for Nature

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EXECUTIVE SUMMARY

Variable renewable generators, such as wind and solar, require electrical energy storage systems because the electricity they supply is not adjustable based on demand. With the cost of renewable-based electricity generation reducing below fossil fuel-based generation, the issue of electrical energy storage is becoming increasingly important to allow for grid stability with increasing penetration of these variable generation sources.

This paper was written to provide background for the APEC workshop on pumped storage hydropower that will be held in early 2021. The paper highlights trends and potential for pumped storage hydropower (PSH) in the APEC economies. The rationale for the focus on PSH is that it is the most mature and economically proven large-scale electricity storage option.

Table 1 provides an overview of the state of renewable electricity generation and energy storage in each of the 21 APEC economies, and Table 2 provides a summary of PSH systems for each economy.

Table 1: Renewable Electricity Generation and Electricity Storage in the APEC economies

ECONOMY	Current renewable energy generation[‡]		Renewable energy target	Energy storage existence (yes/no)	Energy storage planned (yes/no)	Grid reliability issues (yes/no)	Cross-border electricity transmission grids (yes/no/planned).
	TOTAL	PERCENTAGE					
Australia	40,927GWh (2019)	18% of generation	33,000GWh by 2030	Yes	Yes	Lack of investment in flexible electricity generation	Planned - Singapore
Brunei Darussalam	1.2MW (2019)	0.08% of capacity	30% by 2035	No	No	No	Planned - Malaysia and the Philippines
Cambodia[€]	155MW (2019)	~9% of capacity	415MW by 2022	No	Yes	Yes	Yes – Lao PDR, Thailand, Viet Nam
Canada	20GW (2018)	7.2% of capacity	No data	Yes	Yes	No	Yes - United States
Chile	5.8GW (2018)	24% of capacity	60% by 2035	Yes	Yes	Yes	Yes - Argentina; Planned - Andean economies
Chinese Taipei	2.5GW (2015)	1.7% of capacity	20% by 2025	Yes	Yes	Yes	No
Hong Kong, China	118 GWh (2019)	0.3% of generation	7.5% - 10% by 2035; Increase to 15% subsequently	Yes	No	No	Yes - China
Indonesia	9GW (2017)	14.5% of capacity	45GW by 2025	No	No	Yes	Planned - Malaysia
Japan	~181,300 GWh (2017)	18% of generation	24% of generation by 2030	Yes	Yes	No	No
Lao PDR[€]	41MW (2016)	0.656% of capacity	951MW by 2025	No	No	Yes	Yes – Cambodia, Myanmar, People's Republic of China, Thailand, Viet Nam
Malaysia	0.57GW (2016)	23% of capacity	31% by 2025 40% by 2050	Yes	Yes	No	Yes – Thailand, Indonesia and Singapore

ECONOMY	Current renewable energy generation‡		Renewable energy target	Energy storage existence (yes/no)	Energy storage planned (yes/no)	Grid reliability issues (yes/no)	Cross-border electricity transmission grids (yes/no/planned).
	TOTAL	PERCENTAGE					
Mexico	22,543GWh (2018)	6.7% of generation	40% of generation by 2036	No	No	No data	Yes – United States
Myanmar€	173MW (2019)	3% of capacity	12% by 2025	No	Yes	Yes	Yes – Lao PDR and possibly Thailand
New Zealand	~10,300GWh (2017)	24% of generation	100% (including hydropower) by 2030	Yes	Yes	Possible	No
Papua New Guinea	0.075GW (2018)	8.6% of capacity	100% (including hydropower) by 2030	No	No	Yes	No
People's Republic of China	415GW (2019)	21% of capacity	35% of generation by 2030	Yes	Yes	Possible	Yes – Hong Kong, China, Myanmar, Lao PDR, Viet Nam, and Russia Planned – ROK
Peru	2,252 GWh (2018)	4.1% of generation	5% of generation by 2013	No	No	No data	Yes – Ecuador
Republic of Korea	~6GW, including hydropower (2019)	5% of generation	20% by 2030	No	No	No	Planned – HVDC link to China
Russia	3GW (2020)	1.2% of capacity	4.5% of generation by 2030	Under constructi on	Yes	Yes	Yes – CIS economies^, Finland, Lithuania, China and Mongolia
Singapore	~160MW (2018)	0.18% of capacity	8% of generation by 2030	Under constructi on	Yes	No	Yes – Malaysia Planned – Australia
Thailand	21,402GWh (2019)	10.1% of generation	20.77GW by 2037 (26.9%)	Yes	Yes	None evident	Yes – Lao PDR, Cambodia, Myanmar, Malaysia
The Philippines	13,578GWh (2018)	14.4% of generation	15GW by 2030	Yes	Yes	Likely	Planned – Malaysia
United States	2.5 Million GWh (2019)	8.6% of generation	State by state basis	Yes	Yes	No	Yes – Canada, Mexico
Viet Nam	No data	No data	12.5% by 2025 21% by 2030	No	Yes	Yes	Yes – Lao PDR

NOTES

Sources for data included in this table are in the reports for individual economies

‡ Based on most recent data available

^ Commonwealth of Independent States (CIS) economies are: Russia, Ukraine, Belarus, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Armenia, Azerbaijan, and Georgia, and Moldova

€ Cambodia, Myanmar and Lao PDR are non-member economies of APEC. They are included in this analysis because of their importance in the existing and planned regional electricity network that links the Greater Mekong Subregion economies.

Table 2: PSH in the APEC economies (existing, planned and potential)

Economy	Existing PSH capacity (GW)	Planned PSH (yes/no)	Potential PSH (GWh)[*]
Australia	2.5	yes	176,000
Brunei Darussalam	-	no evidence	nil
Cambodia[€]	-	no evidence	8,000
Canada	2	yes	870,000
Chile	-	yes	457,000
Chinese Taipei	0.0026	no evidence	9,000
Hong Kong, China	0.6[^]	no evidence	nil
Indonesia	-	no evidence	821,000
Japan	27	no evidence	52,000
Lao PDR[€]	-	no evidence	188,156
Malaysia	-	no evidence	120,000
Mexico	-	no evidence	1,071,000
Myanmar[€]	-	no evidence	435,000
New Zealand	-	no evidence	40,000
Papua New Guinea	-	no evidence	392,000
People's Republic of China	30	yes	3,767,000
Republic of Korea	4.7	no evidence	36,000
Peru	-	no evidence	553,000
Russia	1.3	no evidence	20,000
Singapore	-	no evidence	nil
Thailand	1	yes	63,000
The Philippines	-	yes	161,000
United States	22.9	no evidence	1,415,000
Viet Nam	-	yes	203,000

Notes:

Except where otherwise noted, sources for data in this table are in the reports for individual economies

[^] Hong Kong's PSH capacity includes an installation located in the People's Republic of China

[*] PSH potential data comes from (RE100 Group, 2021)

[€] Cambodia, Myanmar and Lao PDR are non-member economies of APEC. They are included in this analysis because of their importance in the existing and planned regional electricity network that links the Greater Mekong Subregion economies.

1. INTRODUCTION

1.1. Purpose

This technical paper was prepared to support the *APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply*, and was adjusted following expert input from workshop participants. The workshop was held in February 2021. The workshop was conducted remotely, and was facilitated by the Australian National University, with participant representatives from the APEC economies.

Energy storage is of growing interest around the world because of the rapid growth in renewable energy generation, and the overall purpose of the workshop is to assess development options for PSH as a proven energy storage option. Within this overall objective, the APEC workshop:

(i) Discussed the role of PSH in future electricity systems in APEC and other Mekong economies.
(ii) Helped participants to identify opportunities in their economies for modifying existing infrastructure for pumped storage (e.g. disused mines and existing 'run of river' hydropower facilities).
(iii) Developed participant awareness of sustainability protocols aimed at ensuring PSH systems are developed with minimal negative impacts on people and the environment.
(iv) Provided opportunities for networking and for examining how existing programs can be leveraged to enhance the development of PSH development.

The workshop built on APEC's longstanding interest in promoting the use of renewable energy among its member economies. For example, in 2014 APEC announced that members were incorporating measures achieve an aggregate doubling of renewable generating capacity in the APEC energy mix between 2014 and 2030.. The announcement also referenced other APEC projects focussing on renewables growth, including a low carbon towns initiative based on feasibility testing in the real world (APEC Energy Working Group, 2014). Since then, the APEC Secretariat has published numerous papers focussing on renewables technologies, their integration into mainstream electricity grids, as well as the links between renewable energy and sustainable cities (APEC, 2020).

This technical paper is a revised version of a background paper that was prepared for review by APEC economy representatives at an APEC workshop in February 2021. The revisions to the background paper were based on comments and expert feedback from workshop participants. Based on the outcomes of the workshop, this technical report identifies further opportunities to progress greater use of renewable energy through PSH.

1.2. Background

The term "renewables" in this paper, unless otherwise stated, refers to electricity generation via renewable technologies excluding large-scale hydropower electricity generation.

Over the last decade, the cost of producing electricity with renewables, including wind and solar based production has decreased rapidly while the cost of fossil fuel derived electricity has remained static (Figure 1). In Figure 1, the cost range for fossil fuel generated power is shown as a light brown band (fossil fuel produced electricity has a cost range of \$0.05/kWh to \$0.18/kWh of produced electricity).

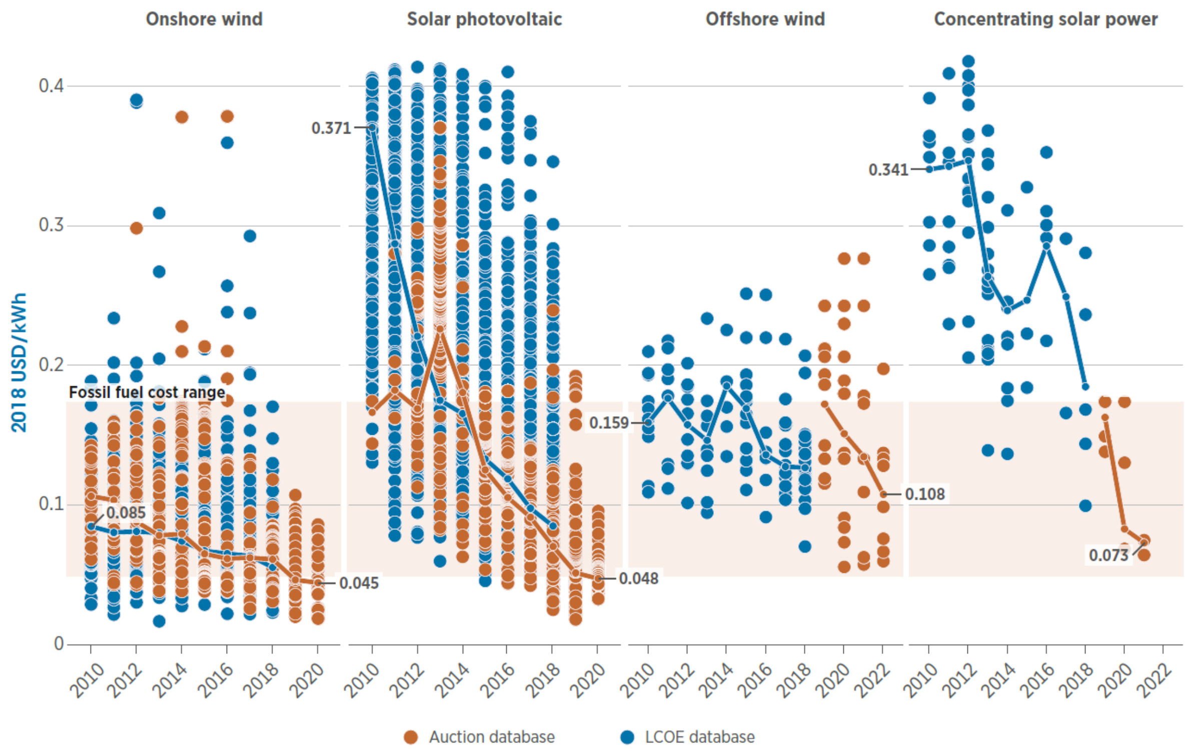


Figure 1: Levelised Cost of Energy production for different renewables, compared with fossil fuel-based systems 2010 – 2020 (Source: (IRENA, 2019a)*)*

The decreasing cost of renewably generated electricity is one driver of growth in installed capacity of renewable generators, however the growing awareness of the need to address the causes of climate change is also driving growth in this area. For example, many APEC economies, including Canada, Japan, New Zealand, the People's Republic of China, the Republic of Korea, and the United States have all announced net zero greenhouse gas emissions targets (Climate Action Tracker, 2020; Dark, 2020; Taylor, 2021; The White House, 2021), although these targets have to be translated into actionable plans to ensure that they are achieved. Despite the need to translate target ambitions into concrete action, the emissions reduction driver is important for two reasons. Firstly, in some circumstances economic (i.e. assessment of the levelized cost of a technology) may be secondary to other considerations such as broader security issues, or government efforts to generate jobs. Secondly, while the cost of renewable energy is falling below the cost of fossil fuel-based electricity generation, the intermittent nature of many renewable energy sources (e.g. solar, wind) raises the issue of energy storage. The cost of energy storage required to make variable renewable energy sources viable must be added to the cost of producing electricity to show the "whole of system" costs of renewable electricity generation *and* storage. However, it should be noted that fossil fuel powered electricity generation is not necessarily immune to the need for energy storage systems. For example, while gas power plants can adjust their output rapidly to accommodate changes in demand, PSH (for example) has been used extensively to buffer electricity output from nuclear and coal-fired power plants.

In terms of variable renewable energy (VRE) sources, PV dominated renewable energy systems have significantly higher energy storage requirement than wind dominated systems. In addition to variation in storage needs between different renewables-based generation technologies, the storage requirements increase as the percentage of VRE in any given energy mix. For example, while different models have derived different levels of electrical energy storage (EES) requirements, even those deriving relatively low EES needs show a rapid increase in EES once VRE (in Europe and the United

States) is contributing more than 40% of electrical energy generation. Despite the range of results reported, in general terms EES power capacity needs (measured in Watts) increase in a linear fashion with increasing VRE while EES energy capacity needs (measured in Watt hours) increase exponentially. (Cebulla et al., 2018). The situation is similar in Australia, with Figure 2 showing growth in requirements for storage as installed VRE grows above 40% or total installed capacity. Shallow storage refers to storage of 1 -2 hours that is required to firm VRE when it makes up relatively small share of total capacity[1]. As the VRE share grows, there is a requirement for medium storage of 4 – 12 hours[2]. The dark blue bands in Figure 2 represent committed PSH with storage of up to 48 hours (deep storage)[3]

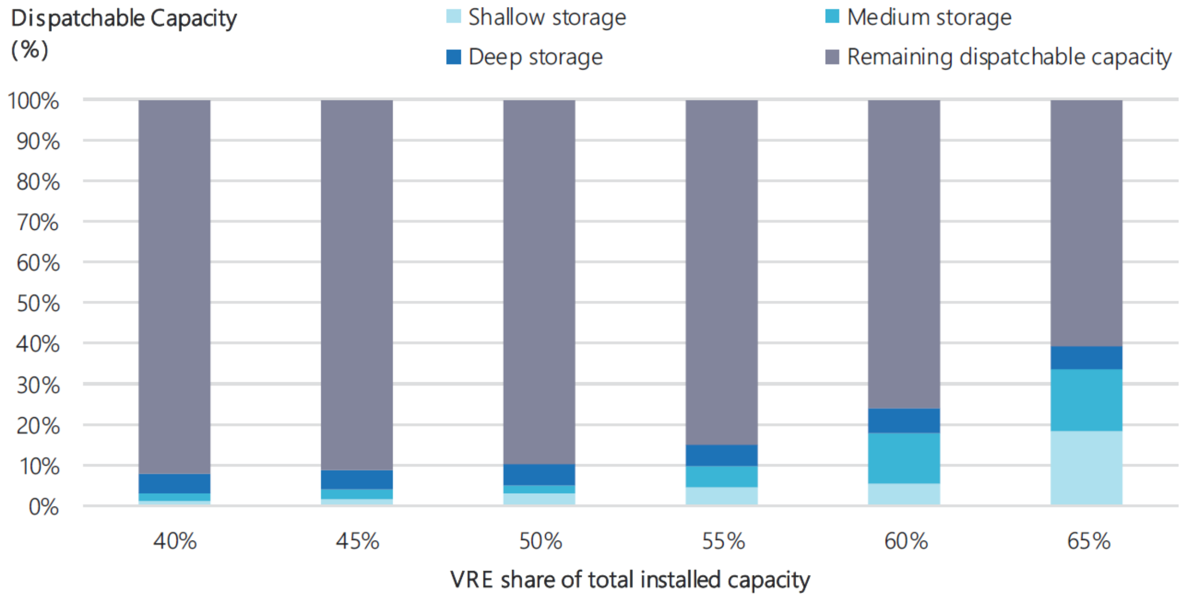


Figure 2: Australian storage capacity requirements as proportion VRE in electricity generation mix grows (Source (AEMO, 2020a))

While Figure 2 refers only to batteries and PSH, there are also other technologies available for EES including flywheels, adiabatic compressed air and thermally stored energy (Table 3). Each EES mechanism has pros and cons, including discharge times (i.e. the time it takes to deplete the energy stored), number of cycles that the technology allows (e.g. a Lithium-ion battery is normally rated to be able to operate for around 1,000 cycles before storage potential degradation limits the battery useability), the efficiency (how much energy dissipates from the EES mechanism), energy density by weight and volume, and of course the capital, operation and maintenance costs. Table 4 provides an indicative range of capital costs as well as operation and maintenance costs for each EES technology.

In terms of levelized cost of energy, generation costs are shown in Figure 1. The cheapest VRE energy production in 2020 is from solar PV (cost range US$0.03 – US$0.10 per kWh of energy production) and onshore wind (cost range of US$0.02 – US$0.09 per kWh of energy production). However, for a full picture of energy costs, the cost of storage also needs to be factored in. While energy storage requirements are situation dependent (with the proportion of electricity generation coming from VRE sources a major factor in determining how much storage is needed), Figure 3 provides an indicative value (in New Zealand dollars) for the energy storage by energy storage capacity for four different EES

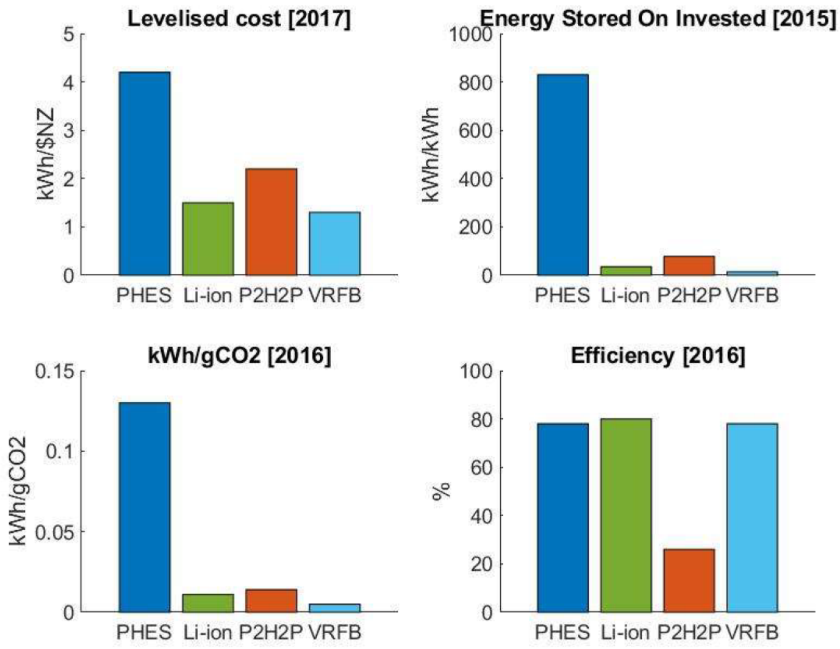
[1] Shallow storage can be provided by batteries and is primarily used for frequency control and ramping
[2] Medium storage can be supplied by large-scale batteries and small-scale PSH. Medium storage is used for intra-day shifting of supply (e.g. production 9am – 3pm, but supply during the evening and nighttime.
[3] Deep storage relies on PSH and is used for so called VRE droughts and for seasonal smoothing of energy.

technologies: (i) PSH, (ii) Lithium-ion batteries, (iii) Hydrogen based storage, and (iv) Vanadium Flow Redox batteries (Table 4). From these four technologies, PSH is the cheapest to construct per kWh (at about NZ$0.25[4] per kWh) and the technology the emits the least carbon dioxide.

The main advantages of PSH are:

(i) flexibility of discharge time (for situations where power will be required from a PSH set-up larger upper reservoirs can be constructed),
(ii) a long useful life,
(iii) low operation and maintenance costs,
(iv) high energy storage per dollar invested to construct the system,
(v) high energy storage compared with carbon dioxide emissions
(vi) not being limited in the number of charge-discharge cycles, and
(vii) having no need to dispose of chemicals and heavy metals that are used in batteries.

While PSH has these advantages, it is suitable for particular situations, whereas other EES technologies are suitable in different situations. For example, battery storage is not as useful for large-scale energy storage, but can have a strong role in regulating power supply because of its sub-second switching speeds (i.e. when there is a sudden requirement for power, batteries can supply the power without there being a lag time) (see e.g. Campbell et al., 2018). In another example, batteries are more useful for households that wish to store electrical energy (e.g. for off-grid households), but PSH generally provides the best option for grid-scale storage.



PHES = Pumped Hydro-electric Storage (in this paper, this technology is referred to as Pumped Storage Hydropower (PSH); Li-ion = Lithium-ion batteries; P2H2P = Power to Hydrogen to Power; VRFB = Vanadium Flow Redox Batteries

Energy Stored on Invested is the ratio of lifetime electrical energy returned by a device compared with the energy to build the device

Figure 3: Comparison of different energy storage options (economic, environmental and efficiency) (Source: (McQueen, 2019)*)*

[4] Based on exchange rates over 2019 and 2020, this equates to around US$0.16 per kWh

Table 3: Main Electrical Energy Storage Systems (ESS) (Source: (EMA (Singapore), 2018, p. 7))

ESS Technology	Description
Pumped Storage Hydro (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.

Table 4 and Figure 3 show details of different economic, environmental and efficiency characteristics for some different storage options.

Table 4: Efficiency, flexibility and costs associated with different electrical storage options (Source: (Berre, 2016))

Technology	Capital Cost (USD/kW)	Flexibility: Discharge time	Efficiency: Self-Discharge per day	Efficiency: Energy Density (Wh/kg)	Efficiency: Energy Density (Wh/Liter)	Useful Life (years)	Useful Life (cycles)	Operating and Maintenance costs
Pumped Hydro	600 to 2000	6 to 10 hours	Negligible	0.5 to 1.5	-	40 to 60 years	-	$3/kW/year
Flywheel Energy Storage	250 to 300	Seconds to minutes	100%	10 to 30	20 to 80	15 years	20,000	$.004/kW/year
Lithium-Ion (Li-Ion) Battery	1200 to 4000	Minutes to hours	0.1 to 0.3%	75 to 200	200 to 500	5 to 15	1,000	-
Sodium-Sulfur (NaS)	1000 to 3000	Seconds to hours	0.1% to 20%	150 to 240	150 to 250	10 to 15	2,500	$80/kW/year
Compressed Air Storage (CAES)	400 to 800	30 to 40 minutes	Negligible	30 to 60	3 to 6	20 to 40	-	$19/kW/year
Lead-Acid (Pb-Acid)	300 to 600	Seconds to hours	0.1 to 0.3%	30 to 50	50 to 80	5 to 15	500 to 1000	$50/kW/year
Vanadium Redox Flow Battery (VRFB)	600 to 1500	Seconds to hours	Negligible	10 to 30	16 to 33	5 to 10 years	12,000	$70/kW/year

1.3. The use of PSH in APEC power systems

PSH is effective as a grid-scale EES solution, particularly as VRE grows a proportion of the total generating capacity. However, PSH sites have to meet certain geographic criteria, including reservoir height differentials and transmission distance, as well as being an economically suitable solution for a given context. For example, Figure 4 shows potential sites for VRE installations, PSH and batteries across a portion of the Australian grid. The figure shows that most of the potential PSH sites are congregated along Australia's Great Dividing Range, a range of mountains that runs up the east coast of the economy, located close to the main population centres. In an example of economic analysis downplaying the potential role of PSH, some authors argue that there is only limited economically viable opportunity for PSH in Viet Nam (EREA and DEA, 2019; Gerner et al., 2017).

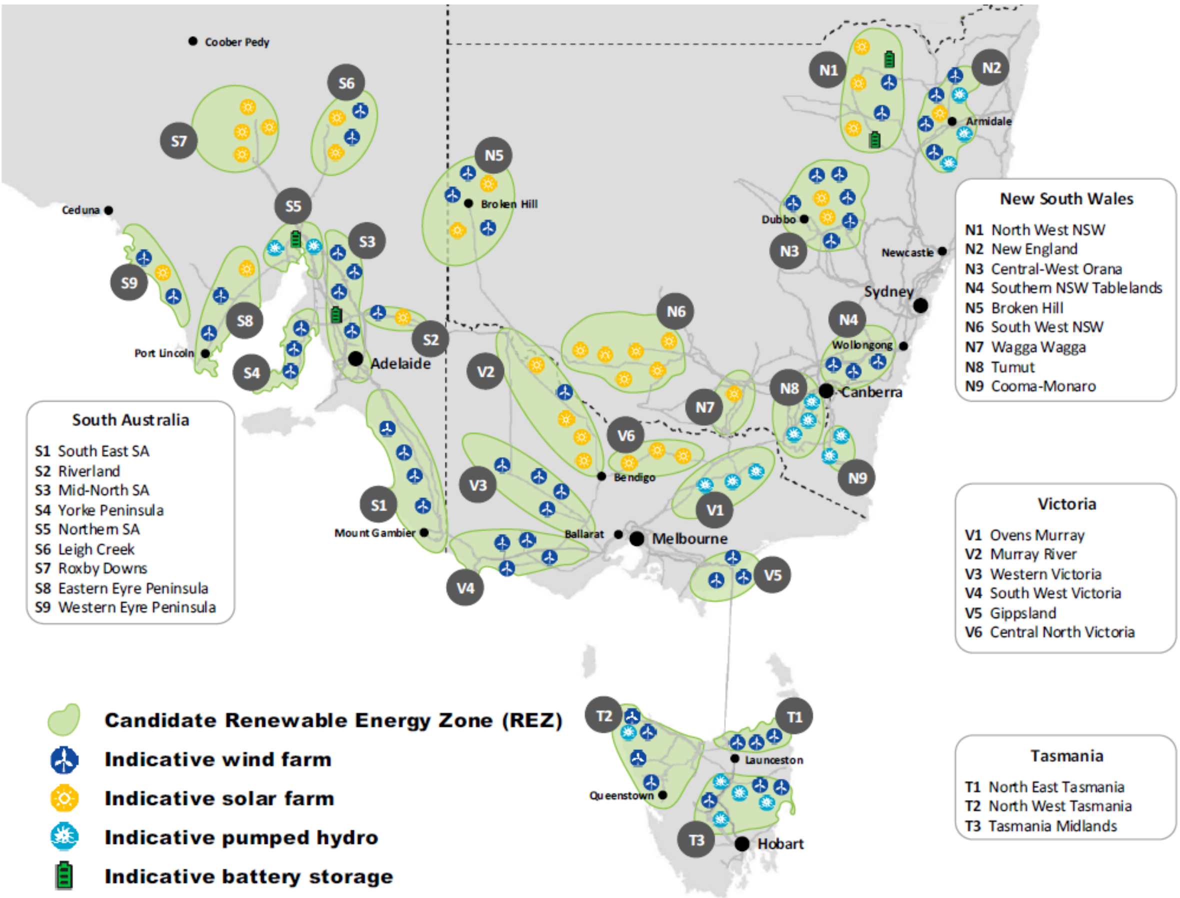


Figure 4: Potential VRE and EES sites in south eastern Australia (Source: (AEMO, 2020a))

1.4. Overview of Pumped Storage Hydropower

The most mature form of energy storage is PSH, which has been in use for over 100 years and has been proven technically and economically (IRENA, 2015a). Globally in 2020, there was around 160GW of installed PSH capacity (IHA, 2020a; Sailer, 2020). PSH systems use two linked reservoirs, and when there is a surplus of electricity available (e.g. when the sun is shining) water is pumped from the lower reservoir to the upper reservoir, and when electricity is needed (e.g. in the evening to run heaters, stoves, hot water systems and lights) water is fed from the upper reservoir through the power plant to the lower reservoir (Breeze, 2018). Figure 5 illustrates how PSH operates, and how it can link with renewable generation such as solar and wind powered generation.

PSH is an established technology that was used well before solar and wind power were significant contributors to electricity production. For example, from 1960 through the 1980s, PSH was installed extensively to add value to nuclear power plants, particularly in the United States and Japan. In the case of both nuclear power stations and coal-fired power stations, PSH has been used to allow generated electricity to meet demand at the right times, because power plants are unable to respond in real-time to rapidly changing power requirements (Antal, 2014; Breeze, 2018). Despite their lack of responsiveness to changing demands, nuclear and coal-based power generation is suitable for providing base-load power, whereas wind and solar PV based generators are not as suitable because of their power outputs vary depending on weather conditions. For this reason, for a household not connected to an electricity grid, solar PV panels on the rooftop need to be connected to an electricity storage system if the occupants want to use lights or electrical appliances at night.

As the cost of renewable power generation continues to fall below that of traditional fossil fuel-based generation, the question of energy storage is becoming increasingly more important. This is so that electricity generated using renewable energy generation technologies can be dispatched to suit demand, rather than being dispatched at the time of production. To address the intermittent production of electricity from renewable sources, PSH is again being recognized as an efficient and proven power storage technology (Antal, 2014). As noted by Hydrowires (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.*

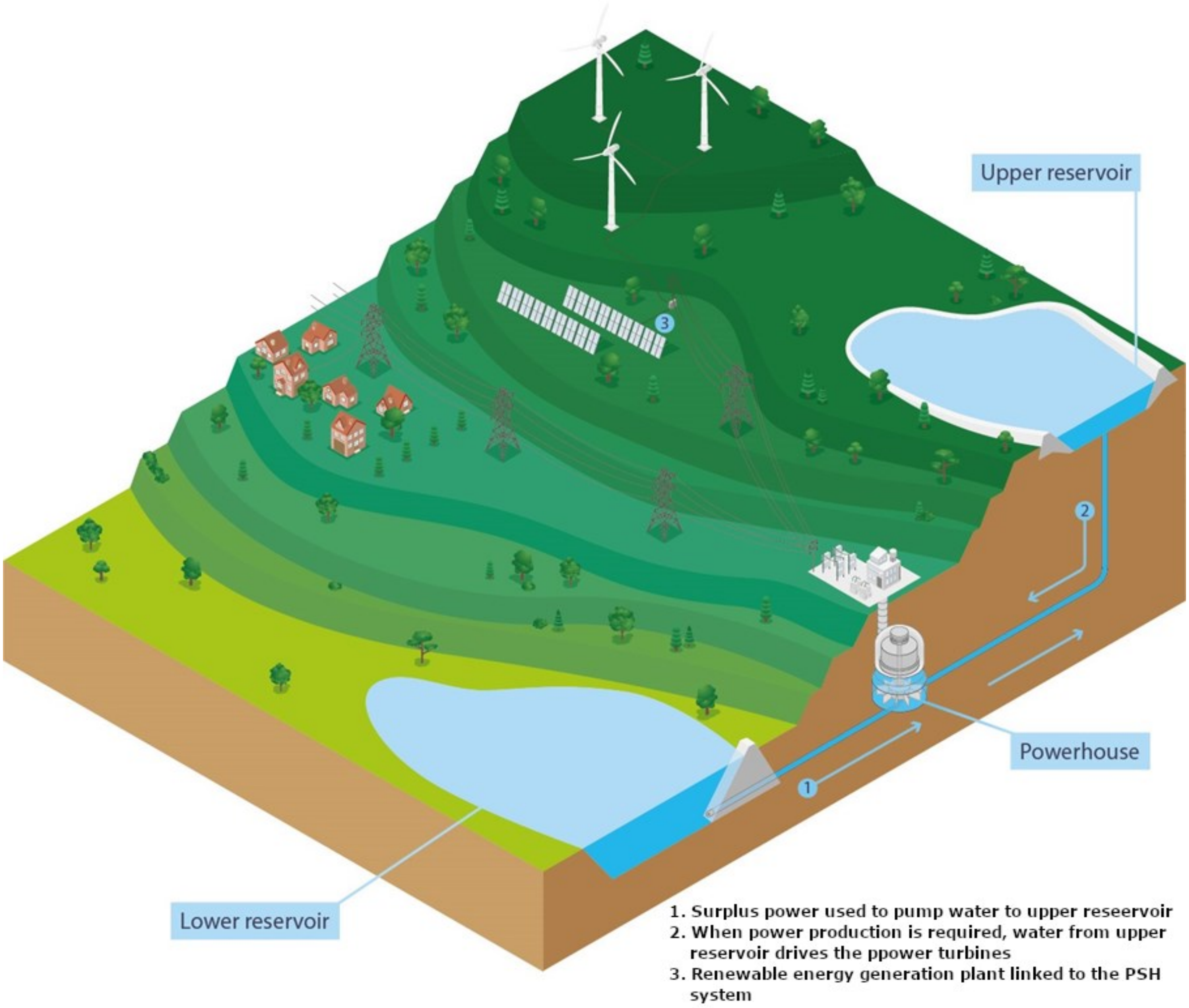


Figure 5: Schematic of a typical PSH configuration (Source: (IHA, 2019a))

1.4.1 Economics of Pumped Storage Hydropower

Business model for PSH

As a large-grid scale energy storage system, it is unsurprising that PSH facilities have long life-spans. Generally, the discounting for investment in PSH is done for 40 years, as beyond this the discounting rate is zero (APEC Workshop on PSH for greater renewable energy use and reliable electricity supply, Plenary Discussion, 2021 (February)). Because hydropower (including PSH) is upfront capital cost intensive, it is very sensitive to the discount rate used. For example, IRENA (2012) observe that for a projected life of 80 years for hydropower projects, that changing the discount rate from 3% to 10% more than doubles the levelized cost of electricity produced. Other factors that affect the cost base are the electrical energy generating capacity (MW), and the energy storage amount (normally referred to in terms of the number of hours that the system can supply electricity at its maximum generating capacity).

The cost of PSH (and other hydropower projects) is also site specific, because the costs of factors such as transporting materials and labour as well as design of dam walls suitable for the site all vary depending on the location. This makes it challenging to make general statements on the business case for PSH. However, the Pacific Northwest National Laboratory (United States) has analysed a range of PSH systems, and provides ranges of capital and operation and maintenance (O&M) costs (Table **).

Table 5: Cost estimates for PSH (Source: (Mongird et al., 2020)

		100MW		1000MW	
Parameter	**Units**	**4 hour storage**	**10 hour storage**	**4 hour storage**	**10 hour storage**
Capital Costs including contingency	$/kW	1,301 – 2,250	1,792 – 2,885	1,093 – 1,889	1,504 – 2,422
	$/kWh	259 - 422	142 - 216	273 - 472	150 - 242
Fixed O&M	$/kW/yr	27.36 – 33.44		16.02 – 19.58	
Variable O&M	$/MWh	0.5125		0.5125	
System Round Trip Efficiency Losses	$/kWh	0.0075		0.0075	

As an example of the economics of PSH, Campbell et al. (2018) prepared a detailed economic analysis of the Snowy 2.0 PSH system currently under development in Australia. This is a 2,000 MW PSH system located in south-eastern Australia. The methodology used was to compare two different scenarios, both analysed with and without the Snowy 2.0 PSH system, in order to quantify the economic costs and benefits. The modelling highlights a number of uncertainties, particularly those related to installation of batteries to support fast responses for peaking generation and incentives for development of renewable generators with storage.

The Snowy 2.0 system is projected to provide sufficient storage for Australia's 'national energy market' (NEM) until the early 2030's, at which time closure of coal-fired power stations and growth in VRE generation will lead to the need for additional large-scale energy storage.

Both scenarios modelled show an electricity price reduction for consumers, with an average price reduction across the scenarios of 5.7% (AUD$4.10/MWh) in New South Wales, with a slightly lower reduction in Victoria. Additionally, the Snowy 2.0 PSH should result in lower volatility of spot prices on the NEM.

Financial advantage from ancillary services

PSH systems should be designed within existing regulatory and market frameworks to take advantage where possible of the ancillary services that they can provide, such as frequency control, voltage regulation, power storage, rapid mode changes and fast ramping speeds, as well as black start capabilities (IHA, 2020b). In addition to these grid related characteristics, PSH is also able to be designed and constructed to desalinate seawater (see e.g. Bellini, 2021), can be co-located with wind or solar generators, including having floating solar generators located on reservoirs, as well as having the potential to use battery systems to smooth electricity production.

Financing and economic mechanisms for PSH

Because PSH is a long-term investment, with anticipated infrastructure lifetime in excess of 50 years, the financing mechanisms and strategies for PSH development are important. Table 6 shows available sources of financing for PSH development.

Table 6: Financing mechanisms for PSH (Source: (Saporiti, 2021))

Types of Financing	Source	Interest	Tenor
Concessionary finance grants or soft loans	Bilateral sources or multilateral development agencies; carbon credits	Very low interest rates	Long term
Public equity	Public investment (Government supported). At times public equity is indirectly funded through bilateral/multilateral development banks	Dividends can start low and increase over time	Indefinite
Public debt	Loans from the Government, public bonds or multilateral development banks	Low; interest rates set by Government or Development Banks	Medium to long-term with optional grace period
Export credit	Finance through Export Credit Agencies	Medium to High	Variable, but commonly short to medium term
Private commercial debt	Private banks, commercial arm of Development Banks	High interest (may be lower in presence of a guarantee)	Short to medium term (possibly extended with guarantees)
Private equity	Private sponsors, private investors, commercial arm of Development Banks	High dividends are expected for risk compensation	Depends on length of concession

Differential between peak and low pricing

PSH has been used historically to provide peaking generation capacity. For example, the Smith Mountain PSH system in the United States began operating in the mid-1960s was constructed to provide economical peaking support (Figure 6), highlighting its suitability to support VRE generation at a system scale.

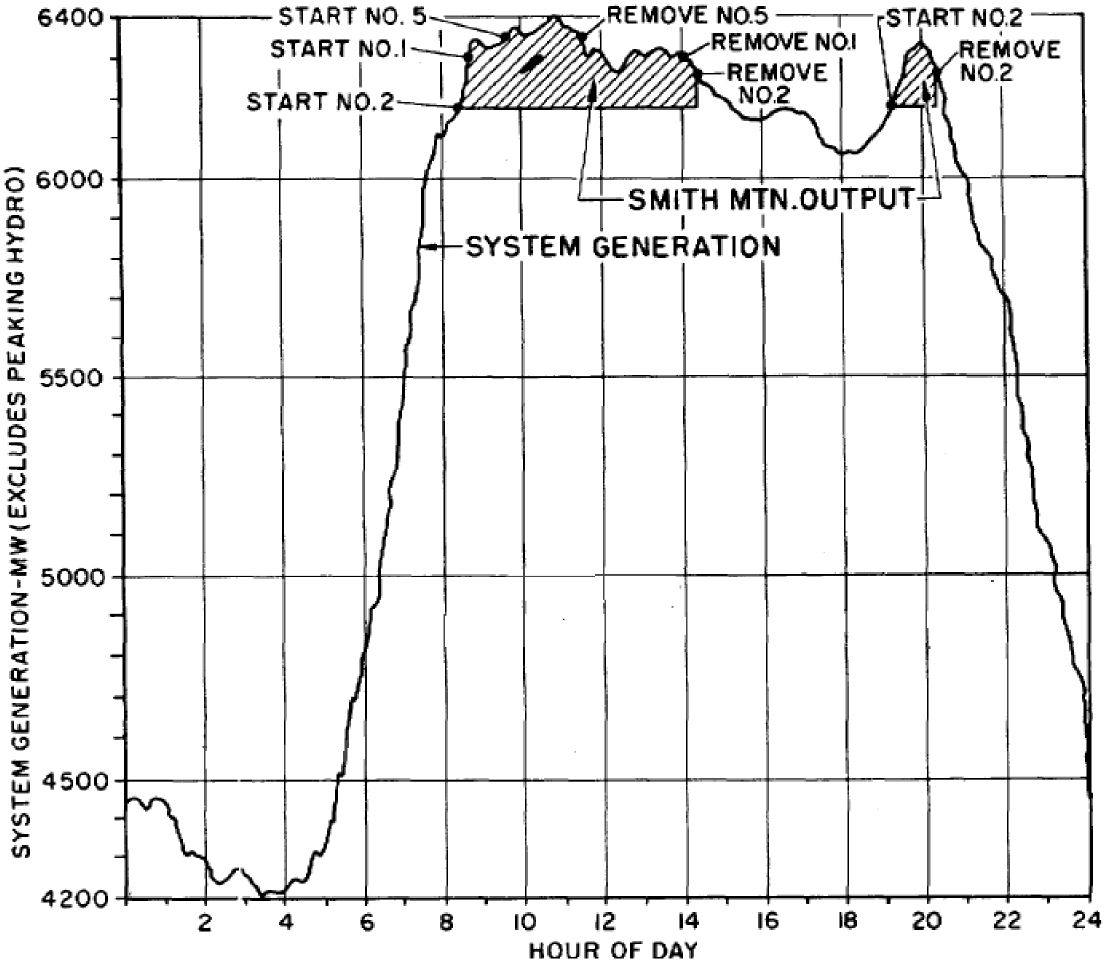


Figure 6: Example of peak generation supplied by Smith Mountain PSH in the United States (Source: (McDaniel and Gabrielle, 1966)

When PSH is used to provide peaking power, as per the example in Figure 6, this supports the economic case for individual PSH developments considerably, as it allows the operator to purchase surplus power when it is cheap (in some cases the wholesale price of electricity can be negative so that the PSH operator is paid to pump water to their upper reservoir), and sell it to the grid when demand and prices are high.

More than 94% of the world's installed energy storage capacity is pumped hydropower storage, and PSH accounts for over 10% of total global hydropower capacity (Breeze, 2018; IHA, 2020a). Figure 7 shows where most of the world's PSH capacity is currently installed.

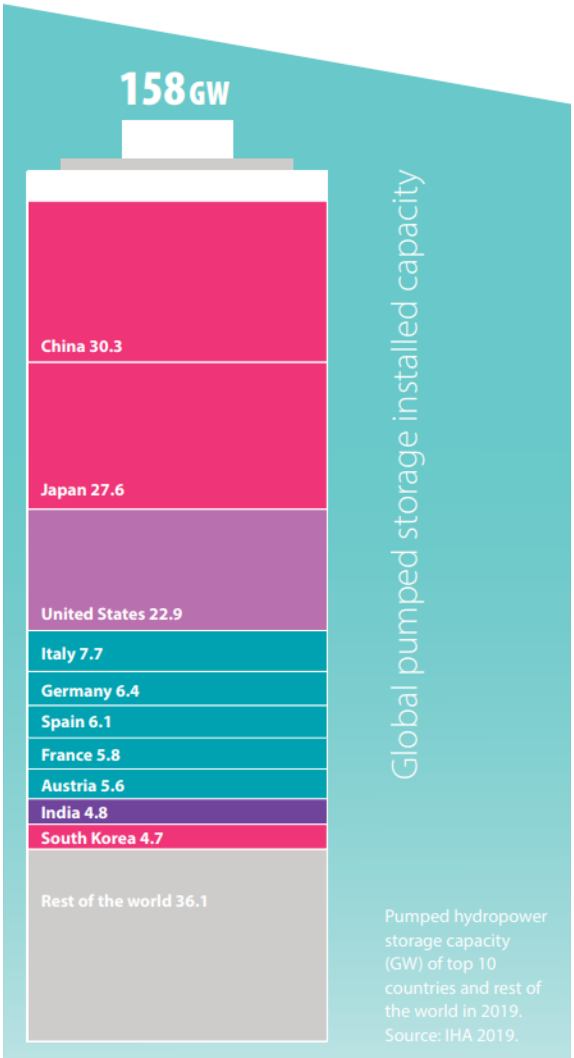


Figure 7: Installed PSH around the world (Source: (IHA, 2020a))

1.4.2 Range of forms that PSH can take

There are some basic criteria for development of a PSH system, which are that (i) there should be a naturally occurring water source available (such as a lake or river)[5], (ii) the facility must be able to connect to an adequate electricity grid, (iii) there must be a sufficient difference in height between the upper and lower water reservoirs in order for the fall of the water to turn the turbines, and (iv) there needs to be enough exchangeable water volume between the two reservoirs (Connolly and MacLaughlin, 2011).

Within these criteria there is wide scope for a range of different forms for PSH systems. They are generally constructed as either open-loop or closed-loop systems. In a closed-loop PSH system, neither

[5] With a closed loop system this may not necessarily be surface water, however the reservoirs must be able to be recharged to account for evaporation and other losses (often sub-surface water is used to recharge the system) (see e.g. Saulsbury, 2020).

reservoir is connected to a naturally flowing water feature (in this case the two reservoirs act as self-contained dams). In contrast, an open-loop PSH system is connected directly to a naturally flowing water feature via the lower reservoir (for example, a dam may be constructed on a river to form the lower reservoir, and with turkey's nest dam constructed on a nearby hilltop) (Saulsbury, 2020).

Because of the flexibility for PSH systems, they can often make use of existing or abandoned developments in ways that can lower the adverse environmental and social impacts, leading to fewer objections from local communities and NGOs. For example, in Northern Queensland, Australia, the Kidston PSH system is being constructed using two existing pits from an abandoned gold mine as the reservoirs. According to the CEO of Genex Power Ltd., the company developing the system, locating the PSH system in the abandoned gold mine has significantly lowered the environmental impacts of the development, meaning the processes of obtaining environmental and social approvals were much simpler than they would have been on a green fields site. Existing and abandoned hydropower dams can also be re-fitted as PSH systems if an upper reservoir can be constructed nearby. In addition to the advantages of using existing facilities as reservoirs, constructing PSH systems on existing sites generally means that access roads already exist. In the case of re-fitting a hydropower dam, the transmission lines are likely to already be in place and the cost of installing the turbines will likely be reduced.

1.4.3 PSH and sustainability

Environmental impacts of off-river PSH systems are generally small. This is because PSH reservoirs do not need to be as big as riverine hydropower systems, and the large number of potential locations means that sites where there will be large environmental (e.g. sites that are ecologically sensitive) can generally be avoided. The reservoirs for PSH systems can be much smaller than the area occupied by an associated wind or solar PV farm. PSH reservoirs can be designed to provide their rated energy capacity for a suitable period of time for a given context. This period is often set in a range between 5 and 25 hours (Stocks et al., 2019). Despite these points, economies of scale will influence the minimum size PSH systems that will be financially viable, with a variety of ancillary factors such as cost of transmission and grid connection affecting this.

Little research has been done into the social impacts specifically relating to PSH. Despite this, similar to social impacts from hydropower projects, PSH impacts can be characterized in three general areas: (i) expansion of towns to service construction, (ii) changes to agricultural production (predominantly relating to irrigation), and (iii) displacement of residents (Vilanova et al., 2020). And, as with environmental impacts, social impacts of PSH systems should be of smaller scale and more easily managed than social impacts relating to hydropower systems in general. The large number of potential sites for PSH noted by Stocks et al. (2019) also means that it should be possible to avoid locations where PSH development would impact negatively on ethnic minority groups or culturally important sites.

1.4.4 Tools to support PSH development

Many tools have been developed to assist with the various aspects of siting and planning PSH projects, including the following:

- The Australian National University had developed a global pumped storage hydropower atlas, and provides siting potential and cost estimates for reservoir pairs for PSH around the globe, based on cartographic modelling. The tool can be accessed at: http://re100.eng.anu.edu.au/global/
- The Pacific Northwest National Laboratory (United States) has undertaken a detailed cost and performance assessment of grid energy storage options, including PSH. The report on this is available at:

https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf

- The International Hydropower Association (IHA) has developed tools to assess sustainability factors related to PSH developed, including social, environmental and governance elements. These tools are designed to be compatible with the International Finance Corporation's Environmental and Social Performance Standards.
    - The IHA sustainability tools are available at: https://www.hydrosustainability.org/
- It often makes sense to co-locate PSH developments with renewable-based electricity generation, such as wind or solar. Global wind and solar atlases are available at the following links:
    - Global solar atlas: https://globalsolaratlas.info/map
    - Global wind atlas: https://globalwindatlas.info/

1.4.5 Opportunities and challenges for PSH

PSH is a mature and well-proven technology for storing electricity. Table 7 details the main opportunities and challenges associated with PSH.

Table 7: Challenges and opportunities for PSH

PSH Opportunities	PSH Challenges
PSH is a mature and proven technology and is the cheapest grid-scale EES option	Greenfield sites: • Loss of land (food production etc…) • Resettlement requirements • Loss of biodiversity and forests • Local opposition to development
Can be co-located with variable renewable energy production such as wind and solar based electricity generators.	Open-Loop PSH: • Changes to flow regimes downstream, including frequently changing water levels • Impacts on littoral areas (erosion, bank slumping) • Changes in sediment loads • Potential impacts on fisheries
Floating solar generators can be constructed on the reservoir surface, reducing required land area required for generation and storage.	Location has to fit criteria for PSH development (which may not be close to demand centres or transmission infrastructure)
PSH systems can be developed in brownfield sites such as abandoned mine pits, or using existing hydropower dams or cascades. • These sorts of projects can have much lower environmental and social impacts than greenfield developments • These sorts of projects can have simpler environmental and social approval processes	

PSH Opportunities	PSH Challenges
The large number of potential sites available for PSH development^ means that sites where environmental and social will be lowest can be selected.	
The use of PSH storage systems can reduce the volatility of wholesale electricity spot prices and reduce the price of electricity for consumers	
PSH systems can take advantage of price fluctuations by purchasing electricity when it is cheap (i.e. excess supply), and selling electricity when demand (and price) is high (section 1.4.1)	
PSH systems have the capacity to provide peaking support, as per the Smith Mountain example in section 1.4.1	
There is support for PSH development through a variety of different financing options (Section 1.4.1)	PSH has high, upfront capital costs
Most of the technology and materials needed for PSH development can be sourced locally, increasing economic benefits	
There are a variety of user-friendly tools to support PSH development, including for siting, costing and assessing sustainability of individual projects	
Open-Loop PSH: • Can be constructed with regulating ponds to ensure continuous downstream flows • Can use existing hydropower systems or cascades (avoiding resettlement and other impacts on local communities, and reducing biodiversity impacts)	

^ (RE100 Group, 2021)

2. ECONOMY-SPECIFIC RENEWABLE ENERGY AND PSH INFORMATION

This section of the report focuses on the situation in each APEC economy individually. For each economy, the following are reported on:

(i) domestic renewable energy targets and trends,

(ii) existing, planned and potential energy storage,

(iii) existing, planned and potential PSH,

(iv) dispatchable power generation capacity and grid reliability, and

(v) cross-border electricity transmission grids.

The APEC economies are reported on alphabetically (e.g. the description for Mexico comes before the description for New Zealand).

In addition to the 21 APEC economies, three additional economies in Southeast Asia are included in the report. These three economies are: (i) Cambodia, (ii) Lao PDR, and (iii) Myanmar. The reason for including these economies is threefold. First, they have important existing and planned electricity network links with APEC economies including Viet Nam, Thailand and Yunnan Province in the People's Republic of China. Second, the three economies, along with Yunnan Province (in the People's Republic of China), Thailand and Viet Nam form the Greater Mekong Subregion (GMS), are all linked together through the joint geography and natural resources of the Mekong Basin. Third, economic growth in this region is on a high growth trajectory, with all the GMS economies projected to have significantly increasing electricity production over the next decade and beyond (WWF, 2016).

2.1 Australia

i. Renewable energy targets and trend

In June 2015 Australia reduced its 2020 renewable energy target from 41,000 Gigawatt hours (GWh) to 33,000GWh (Clean Energy Regulator, 2018). In September 2019 the Clean Energy Regulator reported that the 33,000GWh target had been met (Clean Energy Council, 2020a). However, despite having achieved this goal, the Australian Government has advised that the 33,000GWh target of annually produced electricity will remain in place until 2030 (Department of Industry, Science, and Energy and Resources, 2020). Despite the limited domestic target, in 2019 Australia produced 18% of its electricity from renewable generators, with total renewables-based production of 40,927GWh. Australia's continued growth in renewables-based generation is being driven by households investing in solar PV, and state governments using reverse auctions and other policies such as incentives for home battery storage installation (CEC, 2020).

ii. Existing, planned and potential energy storage

At the beginning of 2020, Australia had an installed energy storage capacity of 25.8GWh, with an additional 1.2GWh planned for installation during 2020. Growth in energy storage in Australia is largely driven by electricity consumers seeking to mitigate effects of rising electricity prices as well as concerns about power outages (SAUR International, 2020). Government funding through the Australian Renewable Energy Agency (ARENA) for energy storage projects is currently being phased out, and with developers requiring larger private equity inputs, combined with uncertainties around grid connection, some authors anticipate that growth in *front of the meter*[6] *storage* will contract in

[6] *Front of the meter (FTM) storage* refers to storage systems used before the electricity enters consumer premises through the meter (utility scale pumped storage hydropower is an example of FTM storage). The alternative is *Back of the meter storage*, which is where consumers install their own storage systems (e.g. a

2022 (e.g. SAUR International, 2020), although others suggest that front of the meter storage is expanding (e.g. AEMO, 2020b).

Energy storage in Australia includes 15 large-scale batteries that were under construction during 2019, such as the 150MWh battery currently being constructed in Wandoan in Southeast Queensland, which is scheduled for completion in mid-2021 (Clean Energy Council, 2020b; Queensland Country Life, 2020).

According to the Australian Energy Market Operator, by 2040 Australia will need between 6 and 19GW of flexible and dispatchable electricity generation/storage in order to back up renewable generation (AEMO, 2020b).

iii. Existing, planned and potential pumped storage hydropower

Australia has around 2.5GW of installed PSH capacity shared among three open loop PSH systems that are located in Wivenhoe, Queensland (500MW), and in Tumut and Shoalhaven, New South Wales (1,800 and 240MW respectively) (Blakers et al., 2010; Pittock, 2019).

Additionally, Australia has many planned PSH systems. Three of the more advanced are summarised here. First is the 2GW/350MWh Snowy 2.0 scheme, which is under construction in southern New South Wales (AEMO, 2020b; Clean Energy Council, 2020b).[7] Second, the state of Tasmania has confirmed feasibility of constructing a 1,500MW transmission line to bridge the gap across Bass Strait, with separates the island of Tasmania from Victoria (Hydro Tasmania, 2020). This will allow Tasmania to pursue its *Battery of the Nation* project, which is modelled to have a capacity of 3,400MW across 14 sites in Tasmania including 1,700MW in three sites where feasibility studies are currently being conducted (Hydro Tasmania, 2019). Third is the Kidston 250MW closed loop PSH system located in northern Queensland. It has been approved for construction, and has an expected completion date of 2022. The Kidston PSH facility will be built in an abandoned gold mine using existing pits. It will have a maximum gross head of 218 metres, an electrical storage capacity of 2,000MWh, and will use two reversible 125MW turbines for pumping and power generation (DoSDT&I, 2019; Genex Power, 2015)

Modelling of PSH potential in Australia indicates it has around 3,000 low-cost sites, with most having a head of 300 metres or more, and with combined energy storage potential of about 163,000 GWh (more than 300 times as much storage as is need to support an electricity system based on 100% renewable generation) (Blakers et al., 2020).

iv. Dispatchable power generation capacity and grid reliability issues

Australia's latest annual energy consumption was 181 Terrawatt hours (TWh).[8] (Australian Energy Market Operator, 2020).

Australia's National Electricity Market (NEM) has not been delivering sufficient investment in flexible electricity generation than can dispatch power on demand. (Australian Energy Market Operator, 2017).

Australia has around 40,000km of transmission lines. The Australian standard on unserved energy usage that says only 0.002% of energy demanded through the grid can be expected to unserved. Currently Australia is meeting this standard comfortably, with only 0.0006% of demand anticipated to be unserved in 2020 (Australian Energy Market Operator, 2020).

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household with rooftop solar may choose to install batteries on their property to store surplus energy, rather than selling it to the grid).

[7] More information on Snowy 2.0 is provided in section 1.4 of this paper

[8] One terawatt equates to one trillion watts (also equal to one million Megawatts or one thousand Gigawatts)

v. Cross-border electricity transmission grids

Australia does not currently have any electricity transmission links to other countries, however development of a 3,711 km high-voltage power line has been approved to link large scale solar arrays in central Australia with Singapore (Recharge, 2020). This link is planned for completion in 2027. Domestically, Australia has a domestic grid that spans state boundaries, although neither Western Australia nor the Northern Territory are connected to this grid (Figure 8).

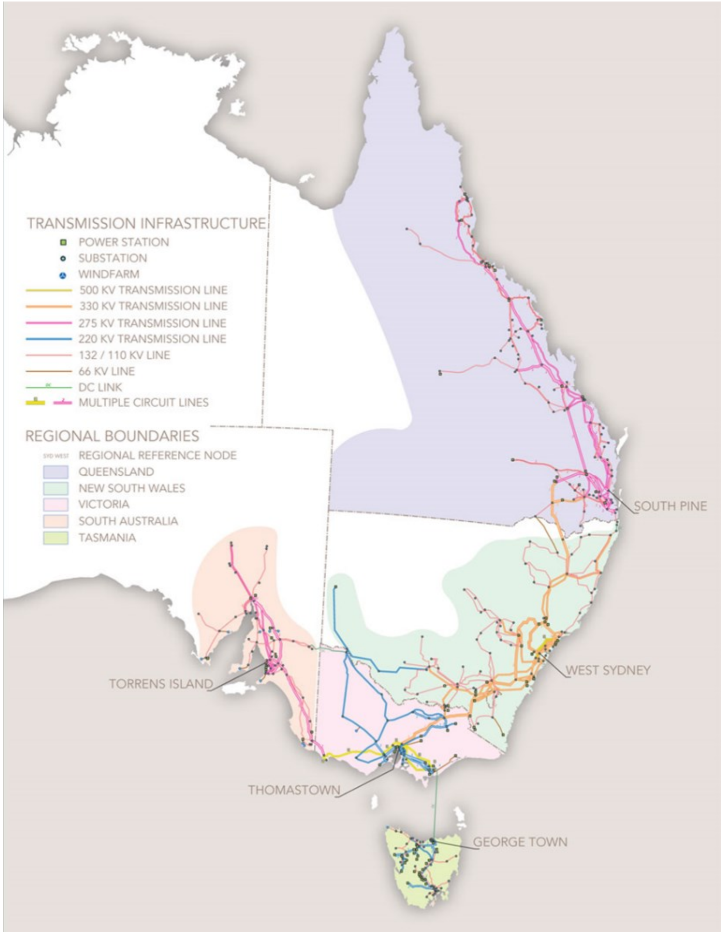


Figure 8: Australia's National Electricity Grid and National Electricity Market (NEM) (Source: https://www.aemc.gov.au/energy-system/electricity/electricity-system/energy-system)

2.2 Brunei Darussalam

i. Renewable energy targets and trend

The economy of Brunei Darussalam has been driven by its oil reserves, however more recently it has begun to invest in renewable energy sources. This has included expanding on the targets set out in the document Brunei Vision 2035. This document was originally published in 2004, with a target of 10% of electricity production from renewables by 2035 (Erdiwansyah et al., 2019b; Pacudan, 2018). However, possibly linked to slump in oil prices between 2014 and 2016 that caused a 70% decline in government revenues, Brunei Darussalam's voluntary report on the sustainable development goals (SDGs) released in mid-2020 highlights an adjustment to the target so that it is currently 30% of electricity to be produced from renewables by 2035 (MOFE, 2020). To achieve this target, the Brunei Darussalam government is focussing on solar installations. In 2011 the first solar array was installed in Brunei, with a peak generating capacity of 1.2MW. An additional 30MW of solar arrays are in the pipeline for installation over the next 3 years (2020-2023), and the target for 2035 is to have 300MW of installed solar (MOFE, 2020). Despite the first solar installation being installed in 2011, in 2019 the international renewable energy agency (IRENA) reported that Brunei still only had 1MW of renewable-based generating capacity (IRENA, 2019b).

Brunei's priorities for renewable energy are (i) develop policy and regulation frameworks, (ii) Scale-up the use of solar PV systems and waste-to-energy schemes, (iii) Raise awareness about renewable energy and develop the human resource capacity in this sector, and (iv) provide support to research and development of renewable energy systems, including technology transfer (Energy Department (Brunei), 2014). Brunei has explored a number of measures to promote growth in renewable energies, including tradable voluntary renewable energy certificates, net metering systems, and feed-in tariffs. These measures are yet to be included in policies and plans, however the government does plan to introduce other financial incentives including subsidies, tax incentives, rebates and direct financial support such as loans for public and private investors (Kan et al., 2018).

ii. Existing, planned and potential energy storage

As of 2017, Brunei had no published plans for storage systems for accommodating the fluctuations in electricity production that are inherent with solar and wind power generation systems (Kan et al., 2018). For example, Brunei's (2014) Energy White Paper only mentions energy storage in terms of storing hydrocarbon based fuel.

iii. Existing, planned and potential pumped storage hydropower

Brunei does not yet have existing or planned PSH (Mishra, 2017).

iv. Dispatchable power generation capacity and grid reliability issues

Brunei's power generation capacity in 2019 was 1.227GW, with 100% of the population having access to electricity (IRENA, 2019b).

v. Cross-border electricity transmission grids

Brunei does not have any cross-border transmission grids, and limited potential to become a part of ASEAN wide power grids. It is anticipated that by 2035 Brunei may have a small (0.4GW) cross border transmission system linking Brunei's grid to the Malaysian grid (ACE et al., 2018). In 2014 the Heads of ASEAN Power Utilities/Authorities (HAPUA) published an ASEAN power grid development update.

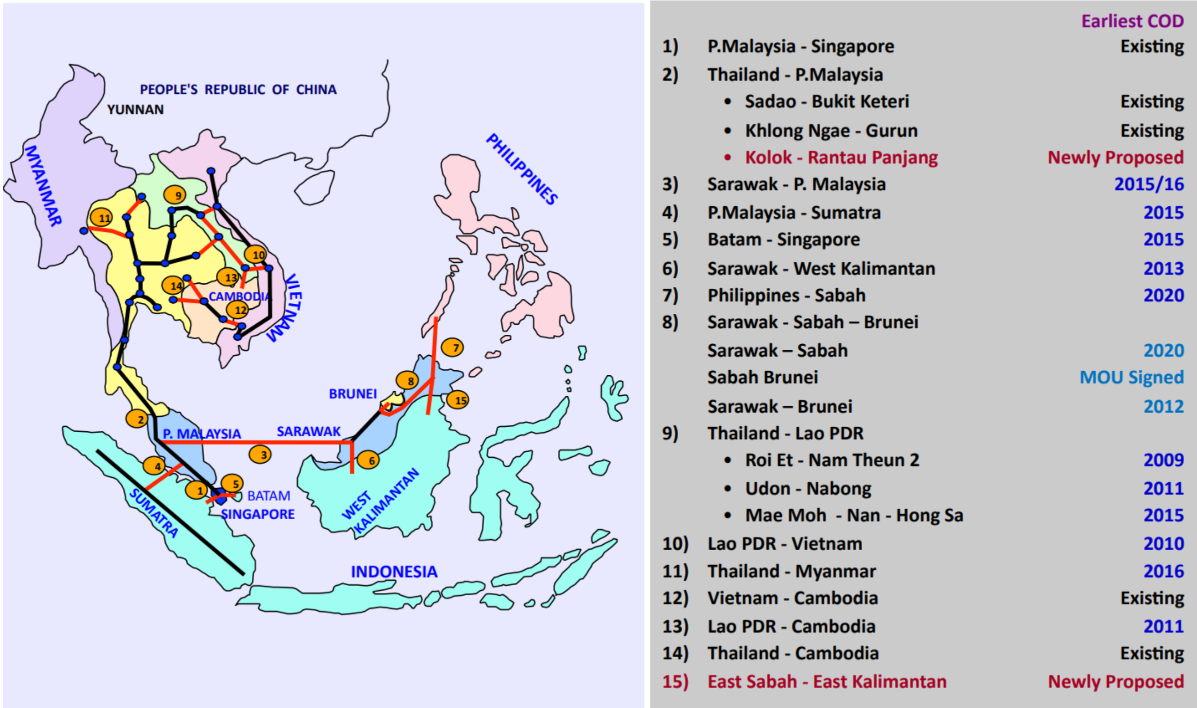


Figure 9: Status of the Development of ASEAN Power Grid Network (2011) (Source: (ASEAN Secretariat, 2011))

Brunei has a very reliable electricity grid (Huang et al., 2019).

2.3 Cambodia

i. Renewable energy targets and trend

In 2018 Cambodia issued rules for integrating solar power into the domestic grid. The rules incorporate a framework to support installation of rooftop solar as well as utility-scale systems, however they were not well backed by financial incentives (Bellini, 2019). For example, in 2018, the Electricity Authority of Cambodia (EAC) issued regulations on the installation of solar arrays that did not provide any information on feed-in-tariffs and only briefly mentioned net metering. These regulations also only allow consumers with a connection of 380 Volts or above to be able to both consume solar generated electricity and sell it to the grid (Hasan and Lin, 2019).

Cambodia's renewable energy generation targets focus on hydropower development, with a goal of reaching 2.2 GW of installed hydropower capacity by 2020, up from an installed capacity of 1,330 MW in 2019 (Erdiwansyah et al., 2019a; IEA, 2019; IHA, 2019b).

There has been limited growth in renewables other than large-scale hydropower in Cambodia to date. In 2019 Cambodia had an installed solar capacity of 155 MW, and has plans to increase this to 415 MW by 2022 (ADB, 2020a).

ii. Existing, planned and potential energy storage

While searches of the literature and the world wide web did not produce any information on existing energy storage, there are plans to begin installing battery storage in Cambodia. On the 11th September 2020 the ADB signed a loan/grant agreement with Cambodia to extend the domestic power grid. This include a grant amount of US$6.7 Million for the development of Cambodia's first utility-scale battery, which will be located next to a 100MW solar farm (ADB, 2020a).

iii. Existing, planned and potential pumped storage hydropower

Cambodia has no existing PSH (IHA, 2019b), however in the context of Cambodia's power planning framework this is unsurprising. For example, background work conducted to prepare revisions to Cambodia's power development master plan recommended that thermal power stations be developed prior to potential hydropower developments in Western Cambodia (The Chugoku Electric Power Co., Inc., 2015). If Cambodia were to pursue EES, and particularly PSH, Blakers et al. (2021) concluded that there is potential to install PSH systems in 190 locations, with a total potential electrical energy storage capacity of 8,000 GWh.

iv. Dispatchable power generation capacity and grid reliability issues

From 2013, Cambodia's annual electricity production has grown at a steady rate, from 1,770 GWh produced in 2013 up to 8,986 GWh in 2019 (CEICData, 2020). The most recent data on generating capacity is from 2016, showing an installed capacity of 1.68GW (3i Cambodia, 2018).

Cambodia's electricity grid has had a number of difficulties in recent years, and is rated as unreliable, with a System Average Interruption Duration Index of 620 minutes per year, and a System Average Interruption Frequency Index of 7.3 interruptions per year (Huang et al., 2019; MME (Cambodia), 2019).

v. Cross-border electricity transmission grids

Cambodia has electrical interconnections with all three neighbouring economies (Lao PDR, Thailand and Viet Nam). Electricity is imported from all three economies, but only exported to Thailand (IEA, 2019).

2.4 Canada

i. Renewable energy targets and trend

Canada has 138 Solar PV installations larger than 1MW, with a combined peak capacity of 1,700MW, with a total solar PV industry peak capacity of 3GW (Government of Canada, 2020a). Installed wind power generating capacity is around four times larger than installed solar PV, with a capacity of 12.8GW (Government of Canada, 2020a).

Biomass is also used in significant quantities for electrical and heat energy production in Canada, most commonly wood derived materials are the biomass source. In 2017 electricity generation capacity from biomass was 4.2GW and heat generating capacity was 1.8GW (Government of Canada, 2020a).

As shown in Figure 10, all non-hydro renewables made up 7% of domestic generation in 2018, with hydropower generating an additional 60% of the economy's electricity.

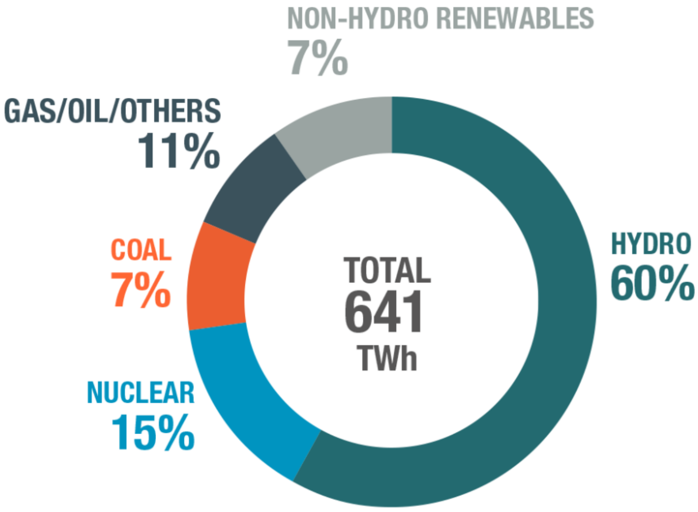


Figure 10: Canada electricity generation by source (2018) (Source: (Government of Canada, 2020b))

However, growth in non-hydro renewables has been growing rapidly, in particular, since 2010 growth in wind and tidal based electricity generation has been substantial (Figure 11).

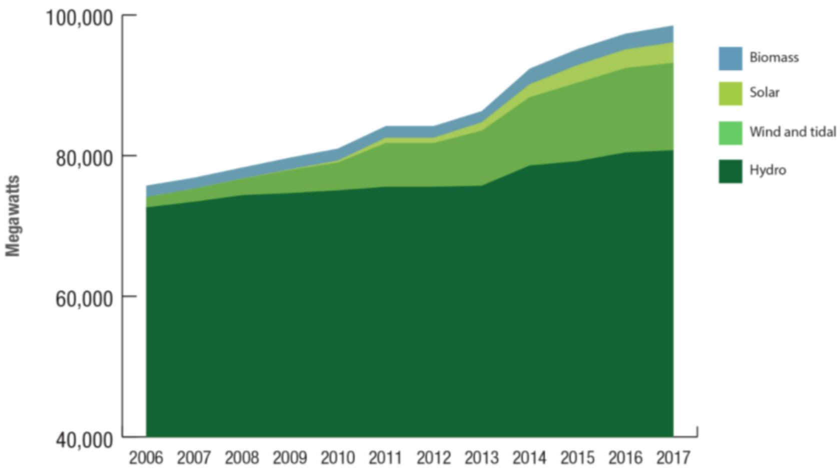


Figure 11: Canada's renewable electricity generation capacity, including hydropower (2006 - 2017) (Source: (Government of Canada, 2020a))

As of 2017, Canada had an installed wind and solar generating capacity of 16GW. While growth for these two forms of generation is expected to slow moving forward, their combined generating capacity in 2040 is projected to be 30GW (Figure 12). At the same time, Canada's energy regulator has announced plans to *phase* out coal-fired power stations by 2030 (Canada Energy Regulator, 2019).

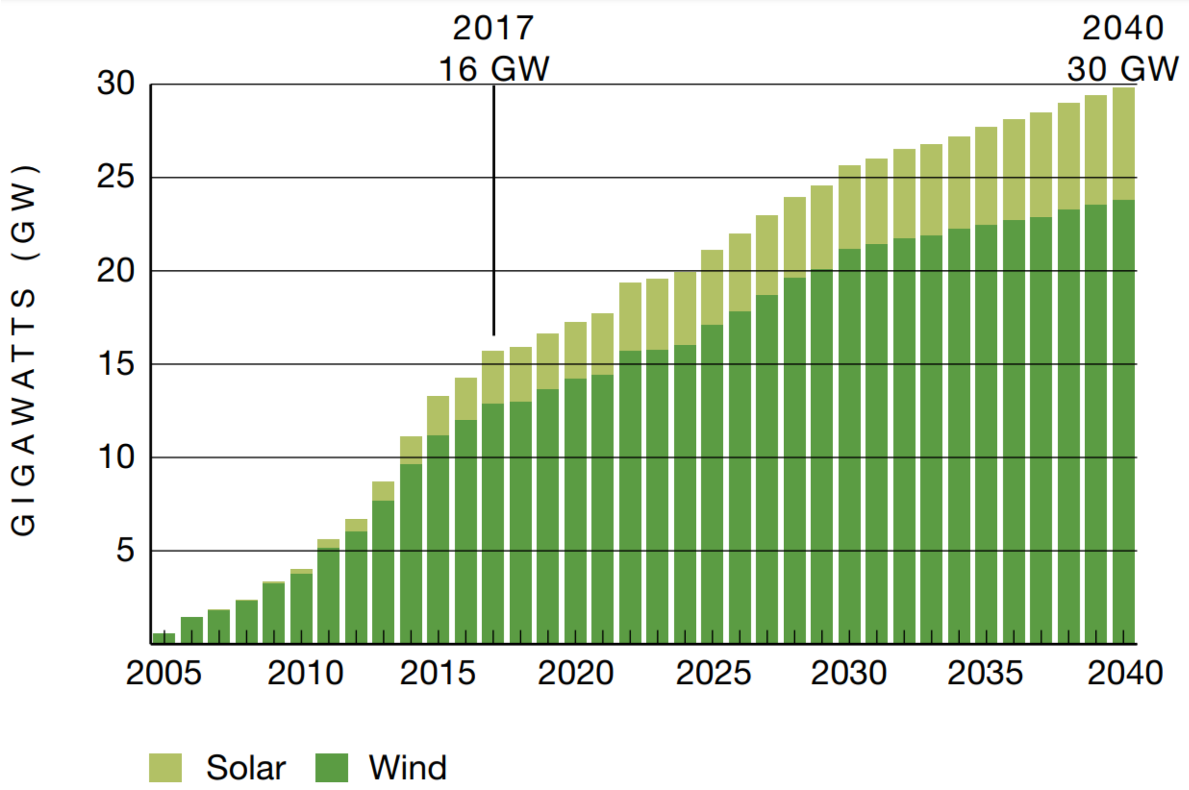


Figure 12: Canadian historical and projected wind and solar generating capacity (Source: (Canada Energy Regulator, 2019))

ii. Existing, planned and potential energy storage

There are 59 operational and demonstration electrical energy storage systems in Canada (Figure 13).

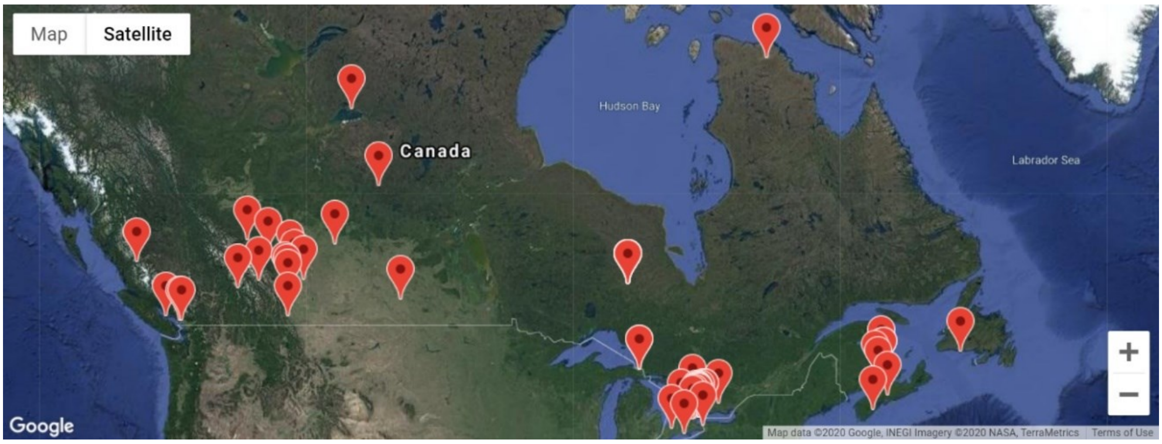


Figure 13: Commercial and Demonstration Electrical Energy Storage Projects in Canada Source: ((Gaede and Rowlands, 2019))

A full listing of these 59 projects is included in Table 8.

Table 8: Canadian energy storage projects

No.	Project	Province
1	Collaborative Grid Innovation for Atlantic Smart Energy Communities (Amherst)	Nova Scotia
2	Collaborative Grid Innovation for Atlantic Smart Energy Communities (Shediac)	New Brunswick
3	Alderney 5 Energy Project	Nova Scotia
4	Pincher Creek Wind Farm (TransAlta)	Alberta
5	Veridian-Tesla Ajax Energy Storage Project	Ontario
6	Toronto Hydro Pole Mounted Lithium-Ion Battery ESS System	Ontario
7	Metrolinx Eglinton Crosstown Maintenance and Storage Facility	Ontario
8	1.75MW NRStor -Hydrostor Incorporated Compressed Air Energy Storage Demonstration Project/ 7MWh	Ontario
9	Colville Lake Solar Project	Northwest Territories
10	Glencore Mine Renewable Electricity Smart-Grid Pilot Demonstration	Quebec
11	British Columbia Remote Community Integrated Energy Project	British Columbia
12	British Columbia Institute of Technology's Energy Demonstration Project	British Columbia
13	Bella Coola Hydrogen Assisted Renewable Power (HARP) System	British Columbia
14	Advanced Biomass Gasification for Heat and Power Demonstration Project, with Storage	British Columbia
15	Revelstoke "Hydro Battery" Project	British Columbia
16	Energy Storage and Demand Response for Improved Reliability in an Outage-prone Community (British Columbia Hydro - Field)	British Columbia
17	Hybrid Energy Container Power System for Project	Saskatchewan
18	Demonstration of High-Level Wind Turbine with Storage (Cowessess First Nation)	Saskatchewan
19	Wind-Hydrogen-Diesel on Ramea Island	Newfoundland and Labrador
20	Stash Energy-Summerside Energy Storage Pilot Project	Prince Edward Island
21	Samsung-Summerside "smart storage" Solar PV System	Prince Edward Island
22	Wind Energy R&D Park and Storage System for Innovation in Grid Integration	Prince Edward Island

No.	Project	Province
23	Nova Scotia Distributed Energy Management System / 'Intelligent Feeder Project'	Nova Scotia
24	Liverpool Wind and Energy Storage Project	Nova Scotia
25	NextEra Red Deer Battery Energy Storage System	Alberta
26	Ghost Pine Battery Energy Storage System	Alberta
27	Wintering Hills Battery Energy Storage Project	Alberta
28	Brazeau Pumped Hydro Energy Expansion Project	Alberta
29	Canyon Creek Pumped Hydro Energy Storage Project	Alberta
30	Alberta-Saskatchewan Intertie Storage (ASISt) Project	Alberta
31	Ambri: Project Energy Bank	Alberta
32	TransAlta Emerging Technologies: TransAlta Commercial-Scale Battery Pilot Project	Alberta
33	Eguana Technologies: Distributed Lithium-Ion Storage for Demand Charge Reduction.	Alberta
34	Drake Landing Solar Community	Alberta
35	Veridian-Ontario-Microgrid	Ontario
36	Toronto Zoo - Ice Energy	Ontario
37	Sir Adam Beck Hydroelectric Generating Station	Ontario
38	Sault Ste. Marie Energy Storage - Convergent	Ontario
39	Renewable energy system Amphora	Ontario
40	Penetanguishene Microgrid - PowerStream	Ontario
41	Panasonic Eco Solutions Canada- Vaughan	Ontario
42	Oshawa Power / Tabuchi Electric - 30 Home Solar-Plus-Storage Pilot	Ontario
43	NRStor Minto Flywheel Energy Storage Project	Ontario
44	North York Energy Storage - Convergent + Temporal 5MW	Ontario
45	2MW NextEra Elmira Grid Battery Storage Facility	Ontario
46	2MW NextEra Parry Battery Storage Facility	Ontario
47	2MW Flow Battery Milton Site	Ontario
48	Marmora Pumped Storage Hydro Project	Ontario
49	Hydrogenics Power-to-Gas	Ontario
50	eCAMION Toronto Hydro Combined Energy Storage Project	Ontario
51	Clear Creek Flywheel Wind Farm Project	Ontario
52	4MW Canadian Solar Solutions Energy Storage Project	Ontario
53	Ameresco Canada Incorporated (2 x 2MW projects)	Ontario

No.	Project	Province
54	660 kW - Toronto Hydro - HydroStor Underwater Storage	Ontario
55	500 kW - Microgrid Research and Innovation Park at University of Ontario Institute of Technology	Ontario
56	5MW / 20MWh - Ontario- SunEdison / Imergy Flow Battery	Ontario
57	2MW / 6MWh ViZn Energy - Ontario Project - Hecate Energy	Ontario
58	150kW Lithium Ion Battery at Ryerson University	Ontario
59	13MW / 53MWh Energy Storage Procurement Phase 1 - Hecate Energy (Toronto Installation)	Ontario

Source: (Gaede and Rowlands, 2019)

Canada has a variety of regulations and other initiatives that include support for sustainable energy storage solutions. Many of these are initiated at the provincial level (e.g. Alberta's energy storage roadmap (2019) or Ontario's 50MW grid energy storage procurement plan (2014)). There are also econonmy-wide initiatives such as the ecoEnergy Innovation fund (initially funded under Canada's 2011 budget) and the sustainable development technology fund (launched in 2001) (Gaede and Rowlands, 2018).

iii. Existing, planned and potential pumped storage hydropower

Canada has around 2GW of PSH systems in development stages across 5 sites (Table 9).

Table 9: Canada's PSH systems under development

No.	Project	Capacity (MW)
1	TC Energy Pumped Storage Project, Ontario	1,000
2	Marmora Pumped Storage Facility, Ontario	400
3	Brazeau Pumped Storage Hydro Project, Alberta	300 – 900
4	Canyon Creek Project, Alberta	75
5	Moon Lake Pumped Storage Hydro Project, British Columbia	25

Source: (IHA, 2020a)

Canada has modest plans for increasing its PSH capacity, with two planned and announced projects with a combined capacity of 475MW (Hydrowires, 2020). Modelling done by Blakers et al. (2021) shows that Canada has the potential to store around 870,000GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

Canada's power generating capacity in 2017 was 147.7GW (UNStats, 2020).

Regulatory oversight of electricity grid reliability is primarily the responsibility of the Canadian provinces and territories (Government of Canada, 2020c). As the Canadian domestic grid has over 30 interconnections with the United States, the two economies have a common *North American Electric Reliability Corporation*, which reported that in 2019 it provided 99.995% reliability (NERC, 2020).

v. Cross-border electricity transmission grids

Canada exports 9% of the electricity it produces to the United States via 34 different transmission lines (Government of Canada, 2020b). Figure 14 shows electricity exports to the United States, as well as imports and the net electricity trade balance between the two economies.

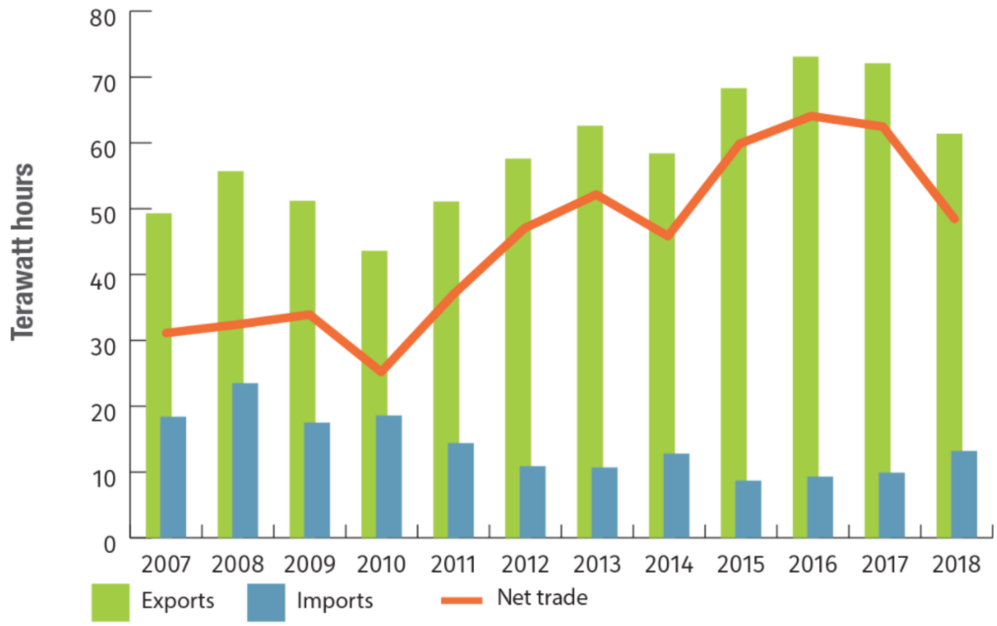


Figure 14: Canada's electricity trade with the United States under purchase contracts (Source: (Government of Canada, 2020b))

2.5 Chile

i. Renewable energy targets and trend

From 2004 Chile began facilitating grid access for renewable generators with its Law 19940, by stipulating that renewable energy producers would not face discrimination accessing the grid. Additionally, facilities with installed generation capacity below 9MW were exempted from transmission fees, and those with capacities between 9MW and 20MW received fee reductions (IRENA, 2015a).

Despite the support for renewables described above, the renewables share of electricity generation fell between 2006 and 2015. Over the period 2006 to 2010 Chile's share of renewable generation, including hydropower, was around 47%. This declined to around 40% for the period 2011 – 2015, but had grown again to 46% by 2018. Excluding hydropower, in 2018 the renewables accounted for 15% of Chile's electricity generation (Acciona and Bloomberg NEF, 2019; Washburn and Pablo-Romero, 2019).

Addressing the falling percentage of renewables in the electricity generating mix, from 2013 the government began promulgating legislation directly supporting renewables. Law number 20698 (known as "Law 20/25") was published in 2013. This law established a target of 20% of electricity generated from renewable sources by 2025, raising Chile's ambition from its earlier 2008 target of 10% of electricity from renewables by 2024 (IRENA, 2015b).

A year later, in 2014, the Chilean government created an electricity auction mechanism tailored to the needs of utility-scale wind and solar generators. The new mechanism used 'time blocks' during the day, and generators bid within these blocks. This allows intermittent generators, using technologies like wind or solar, to offer aggressive bid prices at times when they can best generate power. (Acciona and Bloomberg NEF, 2019). And then in 2015 Chile published its National Energy Policy 2050, which included targets of 60% of electricity generated from renewables by 2035, and 70% by 2050 (IEA, 2020a).

Chile is supported in its goal of growing renewables, because of the abundance of renewable energy resources. For example, Chile's Atacama Desert sees some of the most consistent and among the strongest sunshine on earth, and as a result there has been substantial development of PV solar installations there (Acciona and Bloomberg NEF, 2019).

Providing an example of Chilean investment on PV arrays in the Atacama Desert region, the Almeyda 62MW PV solar farm is pictured in Figure 15.

Figure 15: Almeyda (Chile's second largest solar PV array (2019) - 62MW generating capacity) (Source: https://www.acciona.com/in-the-world/latin-america/chile/)

The change in Chile's energy mix from 2010 to 2018 is shown in Figure 16, showing the rapid growth in wind and solar generation from 2013 onwards.

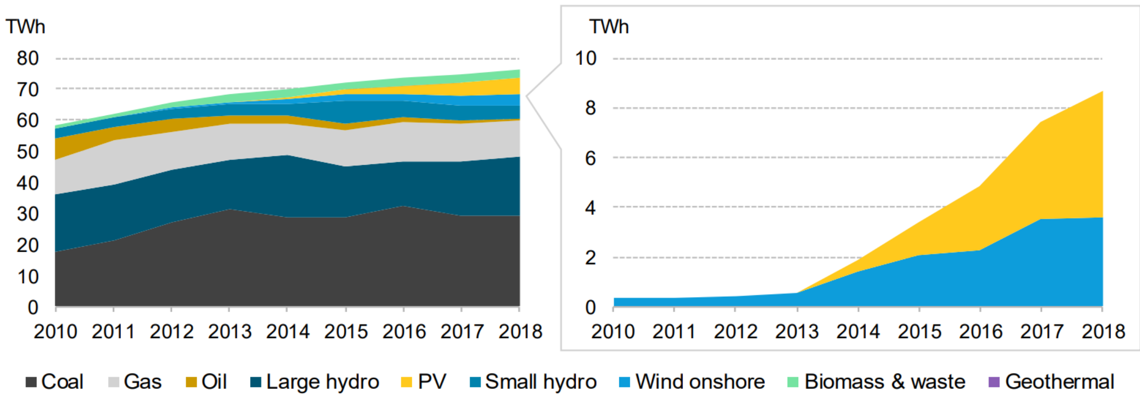


Figure 16: Chile's electricity generation by technology, with detail of wind and PV growth shown on the right (Source: (Acciona and Bloomberg NEF, 2019))

In 2018, excluding large hydro, 24% of Chile's electricity generating capacity was renewables-based (including large hydropower[9], the figure rises to 47% of installed capacity), and in the same year 21% of generated electricity came from renewable generators (Díaz et al., 2020). South America's first geothermal plant began operating in 2017 in northern Chile (in the Atacama Desert), with an installed capacity of 48MW (Díaz et al., 2020). Chile's installed generating capacity and electricity consumption, broken down by generator type, are shown in Figure 17.

[9] Large hydro is any hydropower generating station with an installed generating capacity greater than 20MW (Díaz et al., 2020)

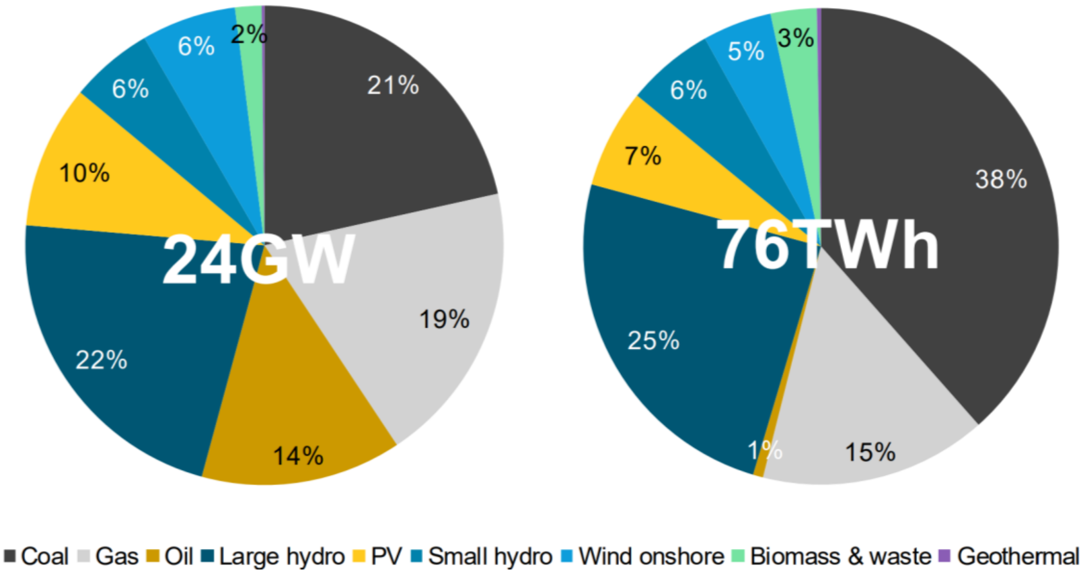


Figure 17: (L) Chile installed capacity, 2018; (R) Chile power generation, 2018 (Source: (Acciona and Bloomberg NEF, 2019))

ii. Existing, planned and potential energy storage

In recent years, growth in variable renewables generation (e.g. wind and solar) has prompted interest in electrical energy storage options in Chile. This has included a variety of technologies. For example, in 2017 Engie Energía Chile signed contracts to install a 2MW lithium ion battery in the city of Arica, in northern Chile (SEI, 2017). In a different example, the Cerro Dominador solar complex has a generating capacity of 210MW, including 110MW of solar concentration energy that has a storage capacity of 17.5 hours (Díaz et al., 2020).

iii. Existing, planned and potential pumped storage hydropower

In July 2019 the Green Climate Fund approved USD$60million to support the Espejo de Tarapacá combined solar and PSH project. The PSH system will be a 300MW pumped storage hydroelectric plant with the Pacific Ocean acting as the lower reservoir; and will be linked to a 561MW PV solar plant. The project is projected to cost a total of USD$1.16 Billion, and has an estimated completion date of 2025 (GCF, 2019).

Modelling done by Blakers et al. (2021) shows that Chile has the potential to store over 450,000GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

Chile has three main power grids, with power generating capacities as listed in Table 10.

Table 10: Power generating capacity in Chile (2020), separated by grid (Source: (Díaz et al., 2020))

Sub-Grid / Type of energy	SEN** (MW)	SEA** (MW)	SEM** (MW)
Renewables	**11,424**	**26**	**3**
Hydraulic Reservoirs	3,354	-	-
Hydraulic Pass	2,812	-	-
Mini Hydraulic Pass	515	23	-
Biomass	507	-	-

Sub-Grid / Type of energy	SEN** (MW)	SEA** (MW)	SEM** (MW)
Wind	1,743	4	3
Solar	2,453	-	-
Geothermal	40	-	-
Non-renewables	**12,594**	**37**	**105**
Coal	5,153	-	-
Diesel Oil	2,963	37	16
Natural Gas	4,479	-	89
Total	**24,019**	**64**	**107**

**SEN = National Electric System; SEA = Aysén Electric System; SEM = Magallanes Electric System

Chile's 2035 goal for grid reliability is that electricity supply interruptions do not exceed 4 hours per year across all three grids, except in the case of force majeure. This target is tightened for 2050, with the goal of no shutdowns for more than 1 hour per year anywhere (Díaz et al., 2020).

v. Cross-border electricity transmission grids

There is a combined cycle natural gas fired power plant in Salta, Argentina, which is connected with the SEN. This generator has a capacity of 643MW. Aside from this, Chile also has plans to become interconnected with the other member economies of the Andean Electric Interconnection System by 2035, as well as to South American economies that are part of the Southern Common Market (Díaz et al., 2020).

2.6 Chinese Taipei

i. Renewable energy targets and trend

In 2009 Chinese Taipei issued their first renewable energy regulation, the *Renewable Energy Development Act*, which had the goal of increasing renewable energy generation to above 15% of total generation by 2025 (Lee and Shih, 2010). Despite this, renewable energy generation did not grow significantly up to 2017, with hydropower growing from 0.26% of production up to 0.36%, and solar PV having grown from 0.14% of production in 2009 up to 0.30% in 2017. Over the same period, Chinese Taipei's fossil fuel-based generation grew from 89.53% up to 93.77% of total electricity generation (Kung and McCarl, 2020). However, the government announced in 2017 that by 2025 nuclear power will be phased out and has prohibited growth in fossil fuel-based generation, meaning renewables will need to fill the 18 Billion kWh (4.3% of production) currently contributed by nuclear generation (Chen et al., 2020). As part of the government strategy to grow renewables generation it has proposed an additional 370 wind farm sites to build on the existing annual wind power generation of 14.7 Million kWh (Chen et al., 2020). Despite the importance of wind generation, the main renewables component that will see them providing 20% of generating capacity by 2025 (under the New Energy Policy) is growth in solar PV systems, which would build on the strong solar PV manufacturing capacity (Fell, 2017).

As of 2015, Chinese Taipei had 2.5GW of installed renewable generation capacity, which was about 1.7% of total generating capacity (ATIC, 2020).

ii. Existing, planned and potential energy storage

Chinese Taipei needs to invest heavily in storage to ensure that the goal of 20% of production from renewables by 2030 is backed up by sufficient storage to make sure the electricity grid remains stable and reliable (AmCham, 2020). Modellers have shown that Chinese Taipei has potential for around 30GW of geothermal energy storage, and the economy has targets of 100MW of geothermal energy storage by 2020 and 200MW by 2025 (Lee and Chang, 2018).

iii. Existing, planned and potential pumped storage hydropower

In 2013 Chinese Taipei had 2.6MW of installed PSH capacity (Lin, 2016). Modelling done by Blakers et al. (2021) shows that Chinese Taipei has the potential to store around 9,000GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

Chinese Taipei plans to increase its share of renewables in its energy mix by adding 20GW of installed capacity between 2016 and 2026. The additional capacity will be made up of 6.3GW of non-hydropower renewables-based generating capacity and 13.8GW of thermal (fossil fuel-based) generating capacity (Bureau of Energy, 2017). A breakdown of the projected percentage of different generation technologies for Chinese Taipei is shown in Figure 18.

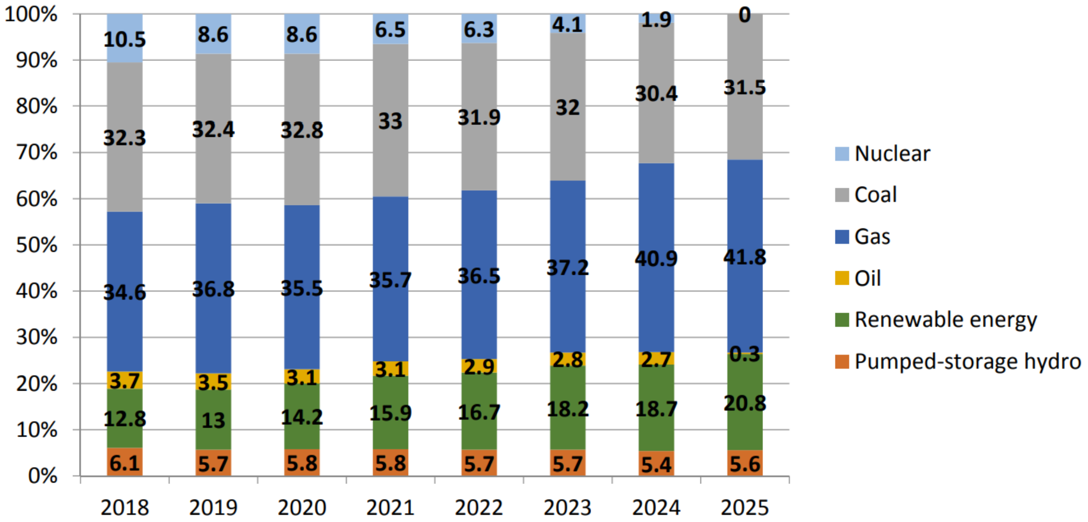


Figure 18: Projections of Chinese Taipei's electricity generating capacity (2018 - 2025) (Source: (Bureau of Energy, 2017))

Chinese Taipei's power grid is largely on the western side of the island. Much of the generating power in the south and central sections of the island, while electricity consumption is dominated by Taipei in the north (Figure 19).

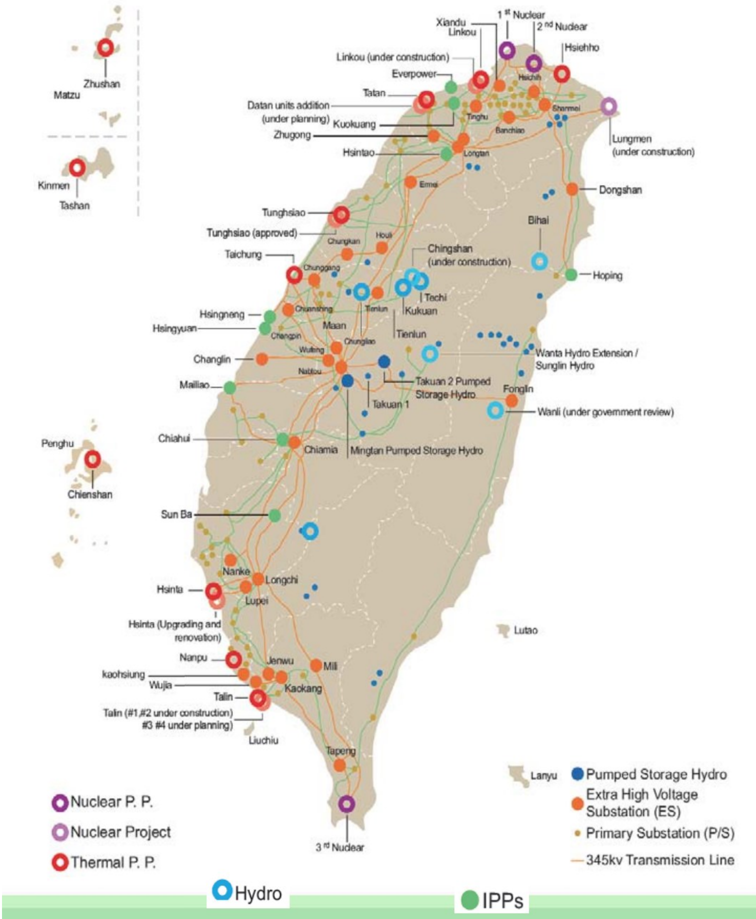


Figure 19: Chinese Taipei: Power system (Source: (Lin, 2016))

As shown in Figure 20, generating capacity in Chinese Taipei has been experiencing some growth since 2004, reaching over 55GW in 2019.

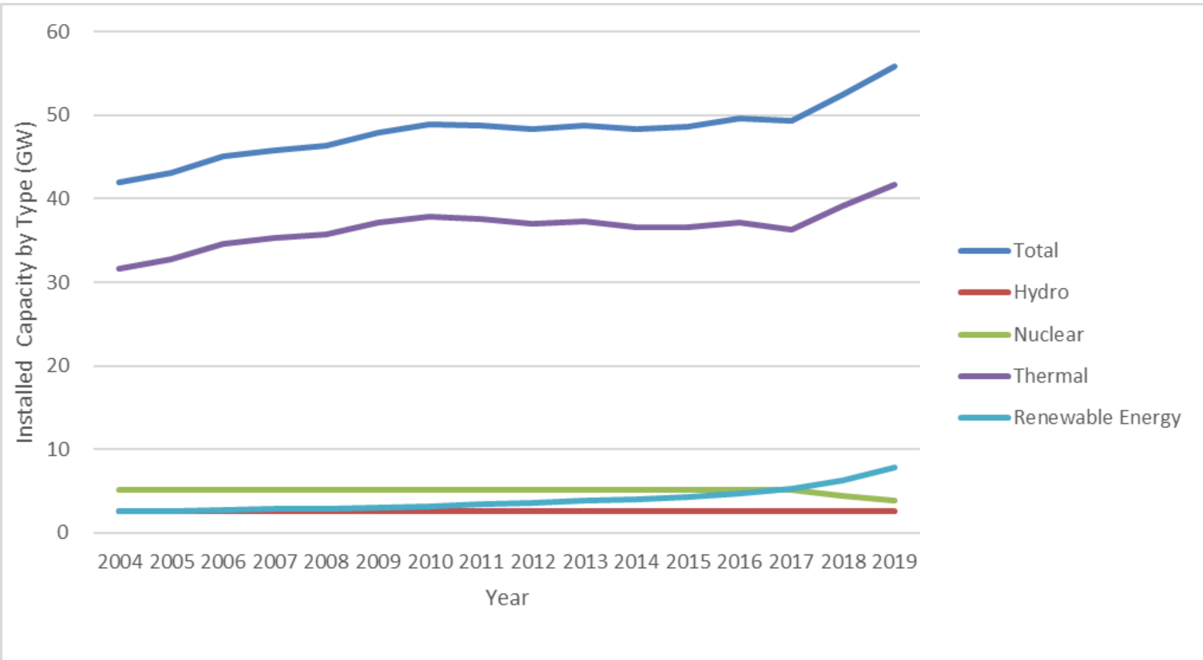


Figure 20: Trends in Chinese Taipei's installed electrical generating capacity (2012 - 2019) (Source: (Bureau of Energy, 2020))

With the move towards renewable energy, there is concern about the electricity reserves held by Chinese Taipei. According to Wu *et al.* (2018), over the period 2012 to 2017 the number of days where the economy's power company (Taipower) issued power supply alerts, because the operating reserve had fallen below 6%, increased steadily from 0 days in 2012 to 102 days in 2017. This included the operating reserve falling below 2% on the 19th October 2016, and event that resulted in wide-spread blackouts as Taipower sought to manage the situation.

v. Cross-border electricity transmission grids

Chinese Taipei is geographically separated by large stretches of ocean from any other economies, and has no cross-border transmission lines (Wu et al., 2018).

2.7 Hong Kong, China

i. Renewable energy targets and trend

Hong Kong, China currently produces 0.3% of total electricity generation from renewable energy sources (EMSD, 2021), and also has rights to power produced at the Guangzhou pumped storage hydropower facility. Hong Kong's electricity generation in 2020 was divided among the different generation sources as follows: coal 24%, nuclear and renewables 28%, natural gas 48% (Carbon Neutral @ HK, 2021)

Given the small size of the territory, and its reliance on fossil-fuel based generation, it is unsurprising that, in 2019, electricity generation in Hong Kong, China was responsible for 66% of total carbon emissions from the territory (Carbon Neutral @ HK, 2021).

In 2017 Hong Kong, China signed Scheme of Control Agreements (SCAs)[10] with the territory's two power companies that proposed the introduction of attractive feed-in tariffs (FiT)[11] for solar and wind generation systems. The SCAs also brought in tradeable Renewable Energy Certificates (GoHK, 2019; WWF Hong Kong, China, 2020). Following the signing of the SCAs, China Light and Power (CLP) and the Hong Kong Electric Company Limited brought in the FiTs in order to encourage investment in both solar and wind power systems in October 2018 and January 2019 respectively. For example, CLP reported FiT's linked to 8.7GWh of electricity generation during 2019, while the Hong Kong Electric Company announced tiered FiTs with the highest rate being HK$5[12] per kWh for systems ≤ 10 kW, and with systems over 1,000 kW to be considered on a case-by-case basis (CLP, 2019; HK Electric, 2019). By the end of 2019 there were about 60 renewable energy installations in Hong Kong, China taking advantage of the FiT scheme, with a total peak generating capacity of 1MW (HK Electric Investments, 2020).

The current sources of electricity generation in Hong Kong, China are shown in Table 11.

Table 11: Hong Kong, China fuel power mix (Source: (Carbon Neutral @ HK, 2021)

Fuel	Percentage of Installed Capacity (%)
Coal	24
Nuclear and renewables	28
Natural Gas	48

[10] SCAs are used by the government of Hong Kong to monitor the performance of the private power companies that supply Hong Kong's electricity

[11] The proposed rate was HK$3-HK$5 per kWh.

[12] HK$1 ≈ US$0.128 ($HK5 ≈ US$0.64)

In recent years Hong Kong, China's ambitions to address electricity sector emissions has grown significantly. For example, in 2017 the territory's Environment Bureau argued that with the state of renewable energy technologies at the time it would only be feasible to generate around 3-4% of required electricity from renewables. However, the 2021 Climate Action Report includes a target of 7 – 10% renewables-based electricity generation by 2035, and up to 15% subsequently, importing clean energy from neighbouring areas and targets for energy savings in commercial and residential buildings (Carbon Neutral @ HK, 2021).

ii. Existing, planned and potential energy storage

Hong Kong, China's Technical Guidelines on Grid Connection of Renewable Energy Power Systems notes that because renewable energy sources are mostly intermittent in nature that ensuring a reliable electricity supply requires either a battery storage system or linkage to a back-up power supply. The guidelines further note that battery storage is problematic because battery disposal can create environmental problems (EMSD, 2016).

iii. Existing, planned and potential pumped storage hydropower

Hong Kong has rights to half of the capacity of phase I of the Guangzhou PSH station (600 MW), which equates to about 4.5% of the economy's total 13.2 GW of installed generating capacity (CLP, 2020; HK Electric, 2021). Modelling done by Blakers et al. (2021) shows that Hong Kong, China itself does not have suitable sites for construction of PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

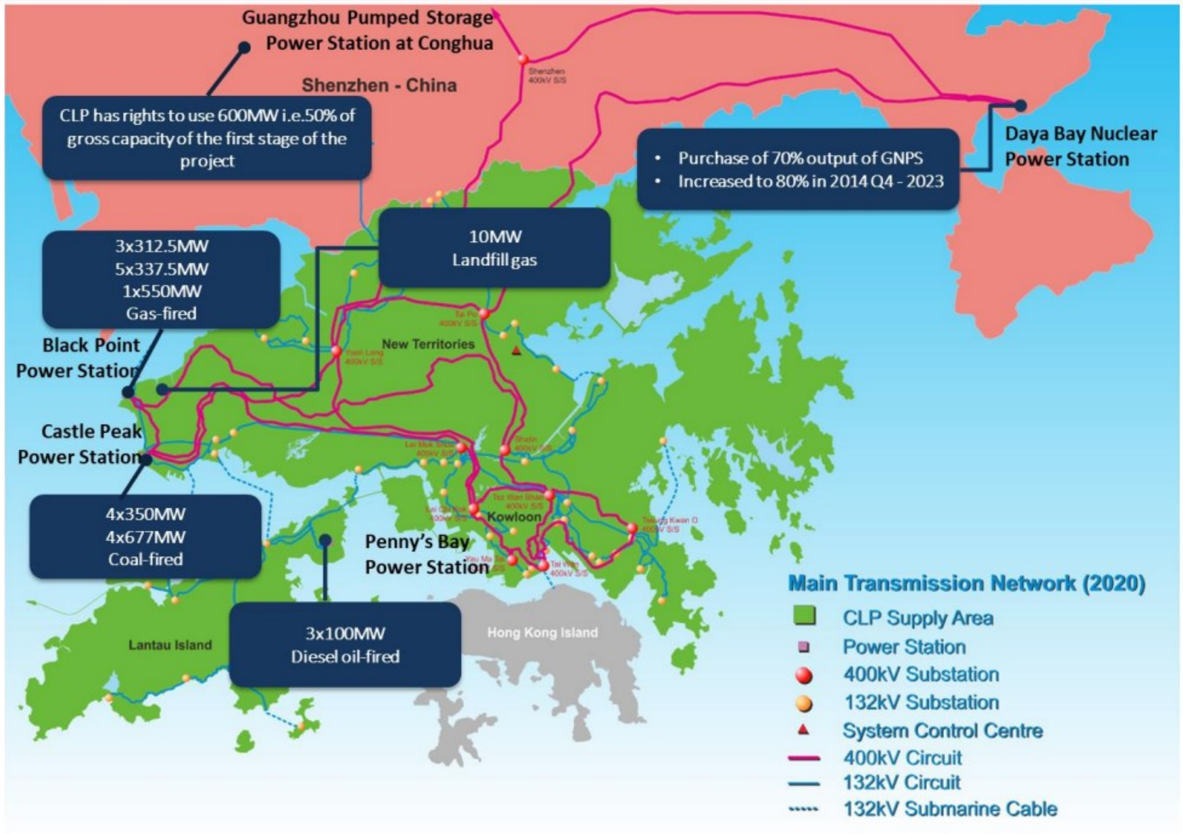
Hong Kong's installed generating capacity, including capacity located in China, is 13.2GW (CLP, 2020; HK Electric, 2021).

Hong Kong Electric's primary carbon emissions reduction method is an increase in gas-fired power stations, to replace coal. The company had 99.9999% supply reliability in 2019 (HK Electric Investments, 2020).

v. Cross-border electricity transmission grids

The Hong Kong, China has cross-border transmission links with China, primarily for the import of electricity from Chinese generators[13] (Figure 21).

[13] Some of these generators are partially owned by Hong Kong enterprises, such as the Guangzhou PSH station



Generation	Transmission	Distribution	Retail
9,573MW installed capacity	> 16,400km of transmission and high voltage distribution lines	235 primary and >15,000 secondary substations	33,963 GWh supplied to Hong Kong in 2020 and about 2.67 million customer accounts

Figure 21: CLP managed power grid, showing cross-boundary transmission from mainland China (Source: (CLP, 2020))

2.8 Indonesia

i. Renewable energy targets and trend

Indonesia's National Energy Policy (Government Regulation No. 79/2014) set the RE target for 2025 at 23% of Total Primary Energy Supply (Stocks et al., 2019), and 31% by 2050 This consists of 69.2 Mtoe for electricity use (~45.2GW) and 23 Mtoe for non-electricity use. By 2050, the target for renewable generation is 31% of the total power generation (Erdiwansyah et al., 2019b). The RE target of around 45GW installed capacity (around 33% of the total installed capacity) in 2025, is projected to come from various RE sources, including the solar energy target of 6.4GW.

In 2018 the government published a ministerial regulation (49/2018) as a guideline to incentivize rooftop solar development, however financial benefits will be challenging to realise under this regulation (Hamdi, 2019). For example, independent power producers (IPPs) trying to take advantage of the regulation must use locally produced solar panels (which are more expensive than imported panels), and they are also forced to match the costs of subsidised baseload coal power (Hamdi, 2019).

Despite Indonesia's published renewable energy goals, and in part because of regulations such as 49/2018, when Indonesia's dominant state power company, Perusahaan Listrik Negara (PLN), launched its 2019 – 2028 electricity supply business plan, plans for installation of solar generation had been reduced from 1,054MW to 917MW (a reduction of 13% from the previous plan (Hamdi, 2019).

Indonesia's total installed renewable generation capacity in 2017 was 9GW (IESR, 2018).

There have been both positive and negative indications with regards to installation of renewable power generation in Indonesia. For example, the investment agreement for Indonesia's first utility-scale wind farm (a 75MW installation in southern Sulawesi) was signed at the beginning of 2017 (Alano, 2017). Despite this however, as of the beginning of 2019, even including rooftop solar, only an estimated 24MW of solar had been installed across the economy (Hamdi, 2019).

One of Indonesia's advantages in terms of renewables generation is that creating a single domestic grid is challenging because of the economy's large number of islands (~17,500[14]), which are spread across a seismically active region. Because of this, renewable based generation plus storage "mini-grids" have begun being installed. For example, the first solar plus storage mini-grids (i.e. not grid connected) were commissioned in 2018 (Tsagas, 2018).

According to data collected and published by the International Energy Agency (IEA), the first time that Indonesia produced more than 1GWh of solar PV produced electricity in a year was in 2010, and for wind it was in 2009 (IEA, 2020b). In Indonesia 1GWh of solar produced electricity equates to less than 1MW of installed solar PV capacity (Stocks et al., 2019). Because of its equatorial location, Indonesia's wind power capacity is low, with a mean wind power of 144W/m^2 for its 10% windiest areas (compared with 1,330 W/m^2 for the 10% windiest areas across the whole globe) (WB Group et al., 2019).

ii. Existing, planned and potential energy storage

There is a variety of literature available that discusses possibilities for storage of electricity in Indonesia, including grid connection of electric vehicles, thermal storage applications, and more generally in articles about overcoming barriers to uptake of solar and wind based generation (see e.g. Burke et al., 2019; Huda et al., 2019; Nasruddin et al., 2020). However, unsurprisingly given the slow growth of renewable generation in Indonesia, searches of the literature and for government documents did not reveal any existing or planned electricity storage.

iii. Existing, planned and potential pumped storage hydropower

Recent research shows that potential for PSH in Indonesia vastly exceeds (by 1,000 times) the requirements for the economy to rely exclusively on renewable electricity generation (Stocks et al., 2019; see also Blakers et al. 2020b). With the large availability of potential sites (see Figure 22), approval authorities and developers can select the sites with the lowest social and environmental impacts.

[14] See (EoRoI (Washington D.C.), 2017)

Figure 22: Potential sites for off-river PSH in Indonesia (Source: (Stocks et al., 2019))

The vast potential for PSH development in Indonesia provides a pathway for rapid deployment of renewables-based electricity generation, with potential PSH sites distributed widely across the archipelago. In this way PSH addresses the challenges of supplying electricity across thousands of islands, through co-location with the mini-grids discussed by Tsagas (2018). Thus PSH can play a strong role supporting Indonesia to raise its emissions reductions ambitions, including to achieve net-zero greenhouse gas emissions by 2050.

iv. Dispatchable power generation capacity and grid reliability issues

Electricity generation capacity in Indonesia has grown steadily over the last five years, and in 2019 reached almost 70GW of installed capacity (Figure 23).

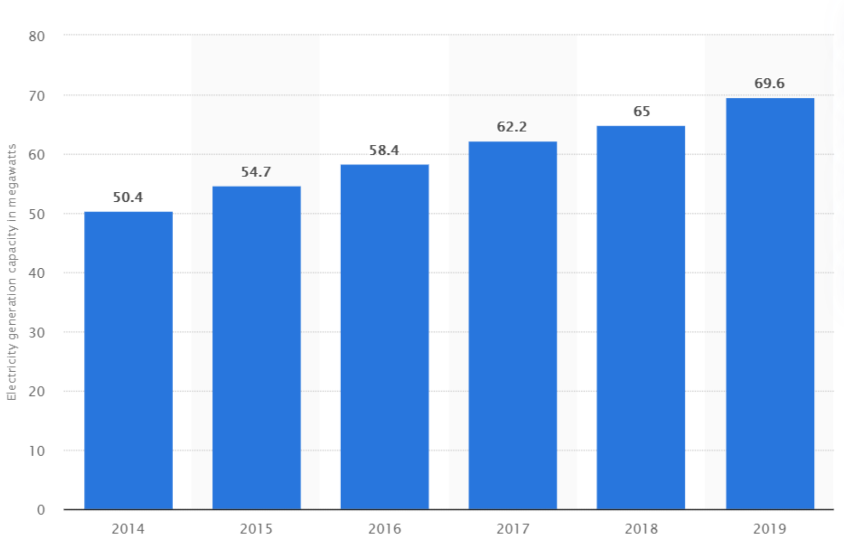


Figure 23: Indonesia's installed electricity generating capacity (2014 - 2019) (Source: (Statista, 2020a))

As an archipelagic economy, Indonesia has a multitude of electricity grids, that are predominantly owned and operated by the state-owned company, PLN (PT Synergy Engineering, 2017). Growth in electricity generation for the eastern island grids in the economy have not kept pace with growth in demand, and in Papua over half the population do not have access to electricity (Cornot-Gandolphe, 2017).

v. Cross-border electricity transmission grids

Indonesia does not have any existing cross-border transmission links into any of its neighbouring economies (Timor-Leste, Papua New Guinea, Malaysia and Singapore), however Malaysia and Indonesia are preparing to establish a high voltage direct current (HVDC) transmission line linking the island of Sumatra (Indonesia) and peninsula Malaysia (Fichtner GMBH, 2020) (See also Figure 24).

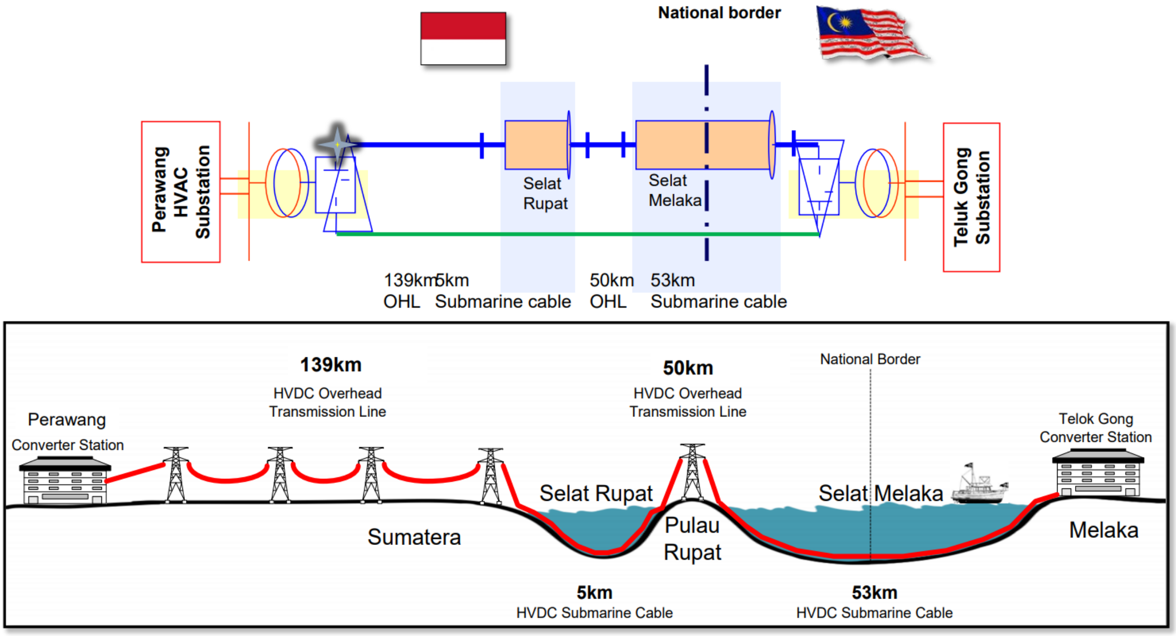


Figure 24: Indonesia - Malaysia transmission line (Source: (Hashim, 2015))

2.9 Japan

i. Renewable energy targets and trend

Japan's growth in renewables-based power generation is driven by two inter-related factors. First, following the Fukushima nuclear power plant accident in 2011, the Government of Japan temporarily phased out its nuclear power generation up to 2013, with nuclear power plants required to comply with updated and more stringent regulatory requirements before being able to begin operating again (METI, 2014). As some nuclear power plants have been able to meet the more stringent regulatory requirements, nuclear power has grown again in Japan as a proportion of the energy mix, and as of 2019 it was producing 6.5% of the economy's electricity (ISEP, 2020). Also related to the Fukushima accident, Japan's 4th Strategic Energy Plan (2014) outlined plans to reduce dependency on both nuclear power, and more broadly including plans to reduce fossil-fuel based electricity production.

Second, the economy's fifth strategic energy plan (2018) includes targets of 22-24% renewable based energy by 2030, and a reduction in greenhouse gas emissions of 26% by 2030 compared with financial year 2013. Since 2014, Japan has seen a steady growth in the proportion of renewable electricity generation (Figure 25).

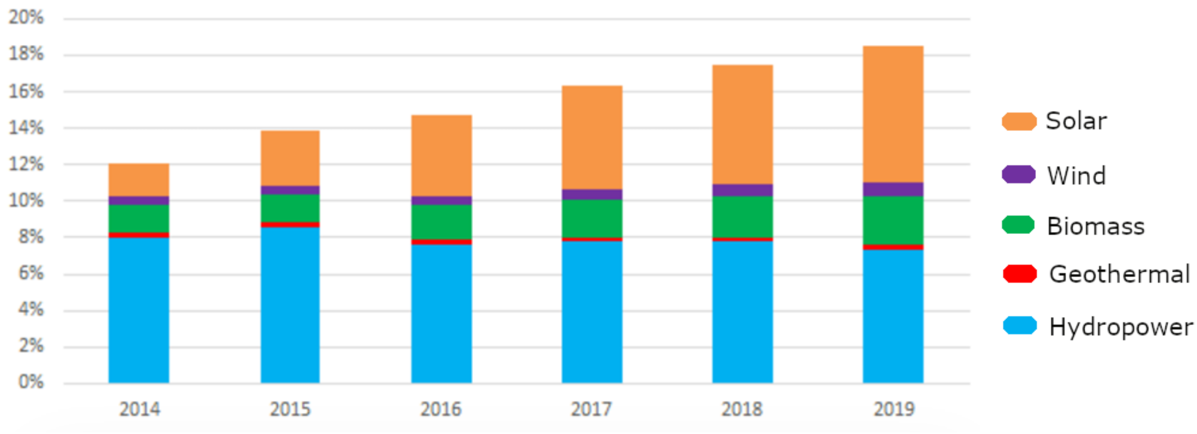


Figure 25: Share of renewable energy as a percentage of total power generation in Japan (2014 - 2019) (Source: (ISEP, 2020))

Using current policies as a basis for their projection, the Renewable Energy Institute projects the steady growth to continue, with total renewable generation in 2030 reaching about 325TWh (Figure 26).

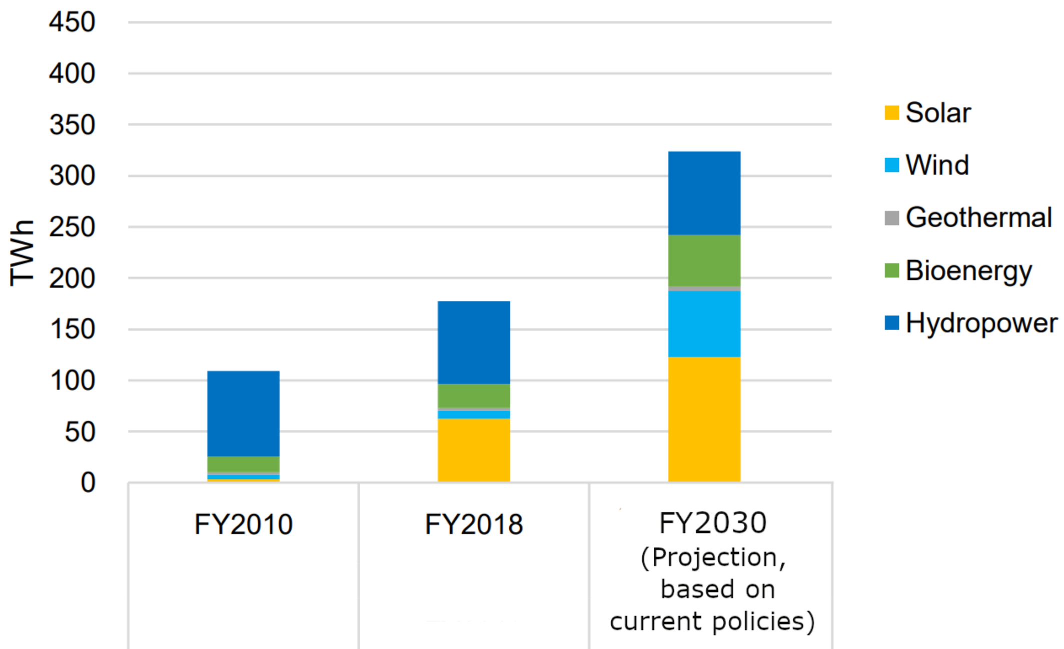


Figure 26: Renewable energy generation projection in Japan to 2030 based on policies in 2020 (Source: (REI, 2020))

ii. Existing, planned and potential energy storage

Since 2014, when Japan published its fourth strategic energy policy, energy storage has been explicitly included as a grid component as a means to ensure regional flexibility and self-sufficiency (Berre, 2016).

In 2019 Kawakami et al. (2019) modelled the potential for energy storage in Japan, based on a 50 and 60% reduction in greenhouse gas emissions in 2050 based on a 2013 baseline.

Table 12 shows the different scenarios and associated storage options that they derived.

Table 12: Modelling of management technology implementation in Japan for surplus electricity in 2050 under different scenarios Source: ((Kawakami et al., 2019))

	Pump-storage	NAS batteries	Li-ion batteries	Water electrolysis	Methanation	FIRES
	GW	GW	GW	Thousand Nm^3-H_2/h	Thousand Nm^3-CH_4/h	GW
C50	25.6	0.4	0.3	47.1	10.6	31.6
C50/Electro	25.6	0.4	0.3	65.5	16.7	26.7
C50/Electro/PV	26.9	0.6	0.3	69.8	18.9	51.6
C60	27.6	23.6	0.8	56.9	15.0	82.1
C60/Electro	27.6	23.0	0.6	73.6	81.2	80.7
C60/Electro/PV	27.6	52.5	0.7	76.8	68.9	85.9

* FIRES = storage of surplus electricity by converting it to heat through electrical resistance, and in which the heat is stored in a thermally insulated tank; NAS batteries = Sodium-sulfur batteries; Li-ion batteries = Lithium-ion batteries; Methanation = Use of electrical energy to drive a chemical reaction to converts carbon monoxide and/or carbon dioxide to methane, which can later be combusted to release electrical energy; Water electrolysis = Use of electrical energy to separate highly pure hydrogen from water, which can later be combusted to release electrical energy.

iii. Existing, planned and potential pumped storage hydropower

Along with the United States, Japan installed a large amount of PSH capacity during the 1970s and 1980s to buffer the electricity supply from nuclear power plants (Antal, 2014; Breeze, 2018). The current existing installed PSH capacity in Japan is the second highest in the world after China, with over 27GW of installed PSH capacity (IHA, 2020a; Sailer, 2020).

Table 13 shows the installed PSH systems in Japan as of 2015 with individual capacity above 360MW (with a total installed capacity in the listed systems of 24GW).

Table 13: Japan's installed PSH systems (2015) (Source: (FEPC, 2015))

No.	Name of Plant	Installed Capacity (MW)	Type
1	Daini Numazawa	460	Pumped Storage
2	Shin Takasegawa	1,280	Pumped Storage
3	Tamahara	1,200	Pumped Storage
4	Kazunogawa	1,200	Pumped Storage
5	Imaichi	1,050	Pumped Storage
6	Kannagawa	940	Pumped Storage
7	Shiobara	900	Pumped Storage
8	Azumi	623	Pumped Storage
9	Okumino	1,500	Pumped Storage
10	Okuyahagi Daini	780	Pumped Storage
11	Okutataragi	1,932	Pumped Storage
12	Okawachi	1,280	Pumped Storage

No.	Name of Plant	Installed Capacity (MW)	Type
13	Okuyoshino	1,206	Pumped Storage
14	Kisenyama	466	Pumped Storage
15	Matanogawa	1,200	Pumped Storage
16	Nabara	620	Pumped Storage
17	Hongawa	615	Pumped Storage
18	Omarugawa	1,200	Pumped Storage
19	Tenzan	600	Pumped Storage
20	Ohira	500	Pumped Storage
21	Shin Toyone	1,125	Pumped Storage
22	Shimogo	1,000	Pumped Storage
23	Okukiyotsu	1,000	Pumped Storage
24	Numappara	675	Pumped Storage
25	Okukiyotsu Daini	600	Pumped Storage

Modelling done by Blakers et al. (2021) shows that Japan has the potential to add an additional 52,000GWh of PSH-based electrical storage.

iv. Dispatchable power generation capacity and grid reliability issues

Japan's electricity generation declined slightly between 2010 and 2017, largely due to a reduction in electricity generated by car producers. (Table 14).

Table 14: Japan power generation (2010 - 2017) by generation type (Source: (SBoJ, 2020))

	Generation Type						
Year	Hydro (GWh)	Thermal (GWh)	Nuclear (GWh)	Wind (GWh)	PV (GWh)	Geothermal (GWh)	TOTAL (GWh)
2010	90681	771306	288230	4016	22	2632	1156887
2015	91383	908779	9437	5161	6837	2582	1024179
2017	90128	861518	31278	6140	15940	2145	1007149

Japan has one of the most reliable electricity grids in the world (Statista, 2020b).

v. Cross-border electricity transmission grids

As an archipelago, with no land borders to other economies, Japan has no international electricity transmission lines (METI, 2018)

2.10 Lao PDR

i. Renewable energy targets and trend

Lao PDR's Renewable Energy Strategy (2011 – 2025) did not include ambitious targets for renewables excluding large-scale hydropower. For example, the strategy called for 73MW of wind power, 106MW of solar power and 400MW of small hydropower by 2025 (Vuola et al., 2020). With these targets, by 2016 Lao PDR had 41MW of installed renewable electricity generation capacity

(Figure 27). Since 2011, the economy has increased its targets slightly, with Khuong et al. (2019) reporting a target of 951 MW of installed renewable capacity (including 33 MW of solar) by 2025.

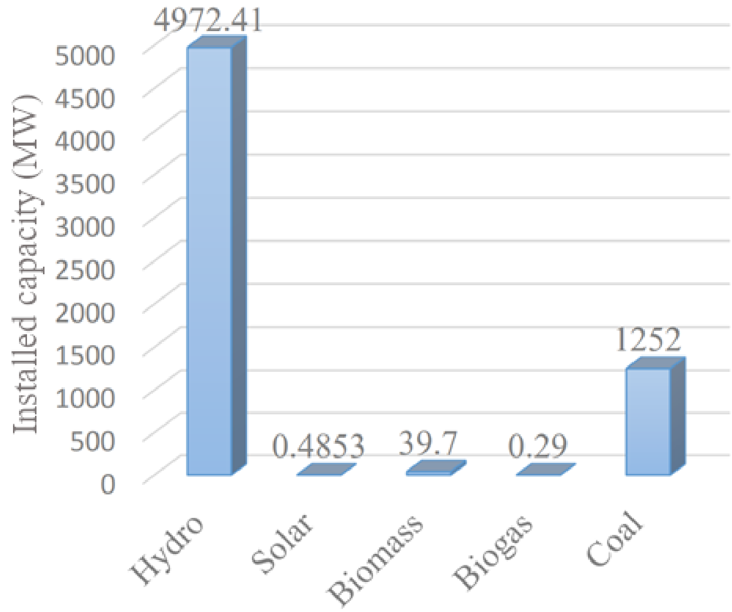


Figure 27: Lao PDR Installed capacity by generator type - 2016 (Source: (Institute of Renewable Energy Promotion, 2016))

ii. Existing, planned and potential energy storage

Searches of the literature, government documents, and the world wide web do not show any existing, planned or announced energy storage facilities in Lao PDR, aside from the storage inherent in the conventional hydropower developments in the economy. While there is some storage in these hydropower developments, the large hydropower dams in Lao PDR are predominantly seasonally varying run-of-the-river dams with limited storage.

iii. Existing, planned and potential pumped storage hydropower

Searches of literature, government documents and the world wide web do not show any existing, planned or announced PSH developments in Lao PDR. Analysis by Blakers et al. (2021) shows that Lao PDR has over 5,500 potential sites that may be suitable for PSH development, with a total potential storage capacity of 188,156GWh. Despite the large number of sites identified by Blakers et al. (2020a), factors such as the market for PSH, including evaluation of the economic case, need to be considered before PSH is developed. For example, as argued by Gerner et al. (2017), there is only quite limited economically viable PSH in Viet Nam despite the assessment by Blakers et al. (2020a) that there are over 6,000 potential sites across Viet Nam.

iv. Dispatchable power generation capacity and grid reliability issues

As would be anticipated with the commissioning of hydropower dams, electricity generation in Lao PDR has grown in a stepwise fashion. In 2019 the economy’s total electricity generation reached 34,410GWh (CEICData, 2020), and as of 2016 the installed electricity generating capacity in Lao PDR was 6.2GW (Figure 27).

Lao PDR has low grid reliability (Huang et al., 2019), and under the economy’s 2015 energy policy the expansion and improvement of the transmission network goals are primarily to facilitate cross-border electricity trade (ADB, 2019). However the economy does have a goal of 95% of households having access to electricity by 2020 and 98% by 2025, with transmission lines extensions and other basic infrastructure development intended to support this goal (ADB, 2019).

v. Cross-border electricity transmission grids

As befitting the economy's ambition to become the "Battery of Asia" (Rujivanarom, 2019), Lao PDR has cross-border transmission links to all five of the economies that it has borders with: Cambodia, Myanmar, People's Republic of China, Thailand and Viet Nam (Figure 28).

Figure 28: Transmission Network of Lao PDR (Source: (ADB, 2019))

2.11 Malaysia

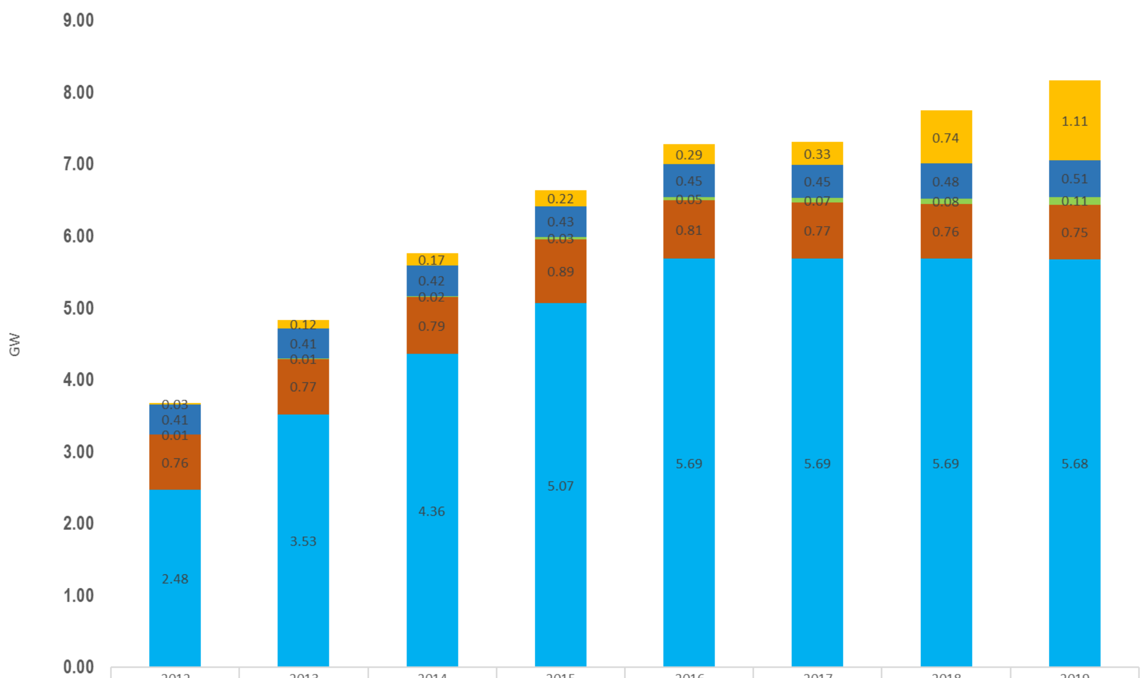
i. Renewable energy targets and trend

Malaysia's renewable energy (RE) endeavour started with three RE policies between 2001 and 2009, i.e. Small Renewable Energy Programme (SREP), Biogen Full Scale Model Demonstration Project (Biogen FSM) and Malaysia Building Integrated Photovoltaic Project (MBIPV). RE sources in focus were biogas, biomass, small hydropower, solid waste and solar PV. With experience from these three programmes, the Renewable Energy Act 2011 and Sustainable Energy Development Authority Act 2011 were gazetted to increase the electricity generation capacity from RE sources via the Feed-in Tariff system (FiT). This was supported in the 10th Malaysian Plan (2010), as well as in the National Budget and the Economic Transformation Programme (2011) (SEDA Malaysia, 2020a).

In 2016, Malaysia published guidelines for integration of Large Scale Solar (LSS) into the electricity network, with revisions made to this in 2018 (Energy Commission of Malaysia, 2018). LSS projects with long-term power purchase agreement (PPA) have been awarded via competitive bidding in several bidding cycles since 2016. This initiative aims to accelerate growth in Malaysia's RE generating capacity.

Further to this, Malaysia also introduced the Net Energy Metering (NEM) scheme in 2016 to encourage solar PV uptake via energy offsetting as an energy prosumer. New CAPEX financing options were launched to reduce the entry cost and barrier for interested applicants. In 2017, Malaysia launched the New Enhanced Dispatch Agreement (NEDA). This programme aims to enhance generation cost and energy efficiency by allowing participation by generators with and without PPA or service level agreement (SLA). Renewable energy plants that qualify may participate as Large Merchant Generator or Price Taker. In terms of financial incentives, Malaysia also offers tax incentives for investments in green energy, as well as green technology finance arrangements with low interest rates (SEDA Malaysia, 2020b).

Excluding large hydropower facilities, Malaysia's installed renewable generating capacity grew from 1.21GW to 2.49GW between 2012 and 2019, with large scale hydropower growing from 2.48GW to 5.68GW over the same period (SEDA, 2021) (See Figure 29 for details). By 2019 Malaysia had 8170MW of renewable energy generating capacity installed (including large scale hydropower), contributing to 23% of the economy's total installed capacity (SEDA Malaysia, 2021). Including large-scale hydropower, Malaysia's updated RE generation target is 31% of installed capacity by 2025, and 40% by 2035 (Ministry of Energy and Natural Resources, 2021).



	2012	2013	2014	2015	2016	2017	2018	2019
Solar	0.03	0.12	0.17	0.22	0.29	0.33	0.74	1.11
Small hydro	0.41	0.41	0.42	0.43	0.45	0.45	0.48	0.51
Biogas	0.01	0.01	0.02	0.03	0.05	0.07	0.08	0.11
Biomass	0.76	0.77	0.79	0.89	0.81	0.77	0.76	0.75
Large hydro	2.48	3.53	4.36	5.07	5.69	5.69	5.69	5.68

Figure 29: Cumulative installed RE capacity Malaysia 2012-2019 (GW) (Source: (SEDA, 2021))

ii. Existing, planned and potential energy storage

As with Indonesia, there are a lack of existing and planned electricity storage systems in Malaysia. However, there is substantial literature investigating electricity storage for Malaysia, and encouraging its use. For example, there have been case-studies designed to highlight the business and environmental assessments undertaken because of the recognition of the need for energy storage (e.g. Laajimi and Go, 2019; Subramani et al., 2017), and there have been cost-benefit analyses done for utilities and consumers (e.g. Chua et al., 2015).

iii. Existing, planned and potential pumped storage hydropower

There is no record of existing or planned PSH in Malaysia (IHA, 2020c). Modelling done by Blakers et al. (2021) shows that Malaysia has the potential to store around 120,000GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

Malaysia's power generating capacity as of 2019 is shown in Figure 30, with a total generating capacity of 35.6GW.

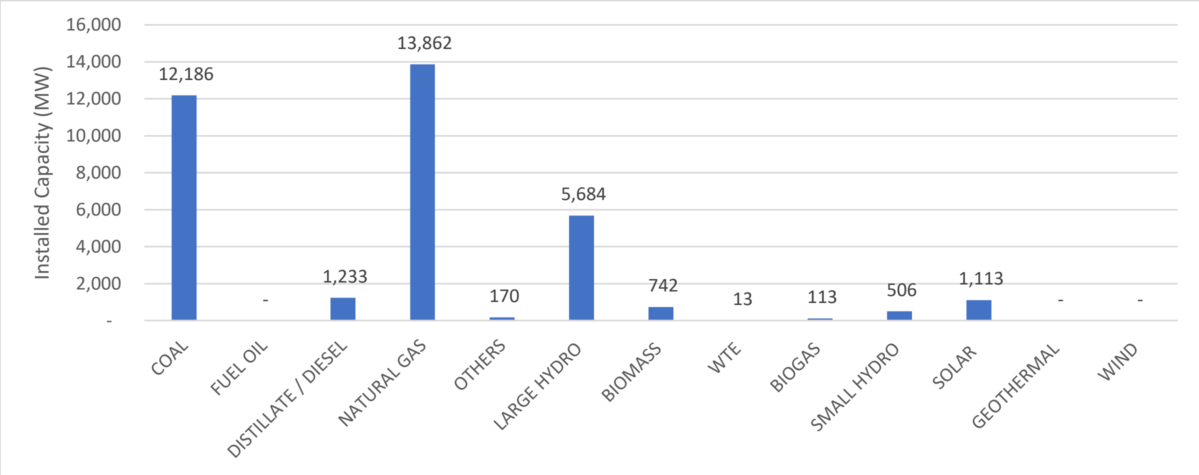


Figure 30: Malaysia's power generating capacity broken down by generator type (Source:(SEDA Malaysia, 2019))

Malaysia' electricity grid has a 99% reliability factor (Huang et al., 2019).

v. Cross-border electricity transmission grids

Malaysia and Thailand established their first electrical interconnection in 1981 with an 80MW capacity, with a second 300MW interconnection added subsequently. The Malaysian and Singaporean grids are linked through the Plentong-Senoko connection (Figure 31).

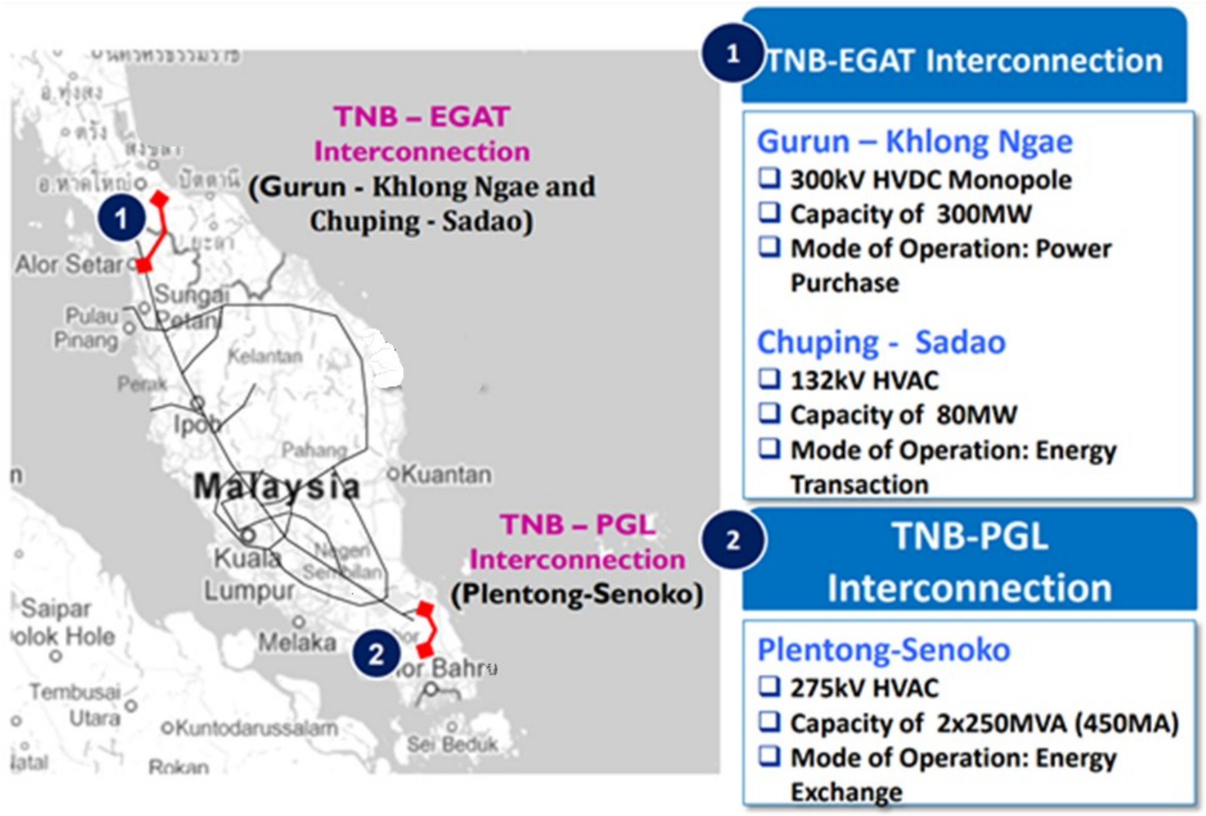


Figure 31: Peninsular Malaysia cross-border electricity transmission links as at 2015 (Source: (Hashim, 2015))

In addition to those links, Fichnter GMBH has been commissioned to establish a transmission link between Sumatra and Peninsula Malaysia (Fichtner GMBH, 2020), with Figure 24 showing the conceptual design.

This interconnection between Peninsular Malaysia & Sumatra is identified under the ASEAN Power Grid initiatives. The project has the objective of enhancing the security of electricity supply of both economies via leveraging on different peak-time between the two economies. The utilities from both economies – PLN and TNB – have embarked on technical and commercial assessment to address the required specification of the development, and to identify the viability to proceed with the project implementation. The project has been considered that a meeting of the ASEAN's Head of Power Utility Authority (HAPUA) Working Group, and is currently in planning phase (SEDA, 2021).

The Malaysian state of Sarawak is connected to Western Kalimantan through a 275KVA transmission line (Ministry of Utilities Sarawak, 2019). Additionally, in 2020 the Sarawak Minister of Utilities announced that the state's northern grid extension project is expected to be completed in 2023, linking Sarawak's electricity grid to both Brunei and the Malaysian state of Sabah (Tawie, 2020). The interconnection between Sarawak – Sabah is tentatively planned to be commissioned in 2023 with capacity of 30MW (reduced from the planned 50MW that had been targeted initially). In 2028, subjected to the 5-year performance of the interconnection, an additional 20MW of capacity will be added to the link, bringing the link capacity up to 50MW (SEDA, 2021).

2.12 Mexico

i. Renewable energy targets and trend

In 2008, the government of Mexico promulgated its Law on Renewable Energy Use and Financing the Energy Transition. This law empowered Mexico's National Electricity Commission to include environmental compatibility in its assessment criteria when choosing to dispatch electricity from among competing generation sources (Sopher and Mansell, 2013). In 2012, with bipartisan support, Mexico passed its General Climate Change Law, which included explicit (but non-binding) targets for renewable-based generation of electricity (Sopher and Mansell, 2013). While these two laws provide frameworks for increasing the share of renewables in Mexico's energy mix, the lack of binding targets undermines their effectiveness. Additionally, there is an expectation in these policies that international funding will underpin their implementation (Sopher and Mansell, 2013).

Mexico published its Energy Transition Law in 2015, which establishes the governance framework for Mexico's energy transition, and aims to regulate sustainable energy use as well as the electricity industry's obligations relating to emissions reductions and transitioning to clean energy generation (Segura and Fernández, 2016; von Lüpke and Well, 2020). The law included tasks and mandates for climate and energy related institutions, however using policies as indicators, some authors argue that there has not been a discernible trend or rising goals for clean energy (e.g. von Lüpke and Well, 2020). Despite arguments such as these, in 2020 Mexico's Secretary of Energy announced a goal of 35% of electricity generation to come from clean sources by 2024 (Secretary of Energy, 2020). This announcement has not yet been enshrined in policy and did not specify whether clean sources would be restricted to renewable generation. The most recent policy goal for renewable generation of electricity was a target of 40% of electricity generated from renewable-based generators by 2036, as included in Mexico's mid-century climate change strategy (SEMARNAT-INECC, 2016).

Mexico has strong potential for renewable electricity generation. First, there is a large temperature difference between the surface temperatures of the Gulf of Mexico and the Pacific Ocean, and this creates a 'wind tunnel' effect in Mexico's Oaxaca region that makes it suitable for large wind farms (Mele, 2019). For example, IRENA (2015c) reports that there is 30GW of potential for on-shore wind generation to be installed in Mexico with an average capacity factor of 35%. Secondly, northern Mexico has high levels of solar irradiation comparable with the deserts in North Africa and with California. In addition to wind and solar, Mexico also has already installed more than 10GW of hydropower capacity, and around 1GW of geothermal power generation (Gutiérrez-Negrín et al., 2020; Mele, 2019).

In 2018, Mexico generated 22,543GWh of electricity from renewables-based generators, a total of about 6.7% of all electricity generated (IEA, 2020c).

ii. Existing, planned and potential energy storage

It is recognised that, with increasing renewable electricity generators, energy storage is required to ensure grid reliability, flexibility and security. However energy storage systems are yet to be used in Mexico, with energy policies only giving cursory consideration to them (Diezmartínez, 2021).

iii. Existing, planned and potential pumped storage hydropower

Mexico has not existing, planned or announced PSH systems (IHA, 2020c). Modelling done by Blakers et al. (2021) shows that Mexico has the potential to store over 1,000,000GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

Mexico's power generation capacity in 2015 was about 62.5GW, and this had risen to about 70GW of installed capacity by 2018, and in 2018 a total of 317,278GWh of electricity was generated (Gutiérrez-Negrín et al., 2020). Searches of the literature and of government websites has not revealed any data on grid reliability.

v. Cross-border electricity transmission grids

Mexico and the United States have intersecting electricity grids in 11 places, although the majority of these have a transmission capacity of less than 100MW (Figure 32).

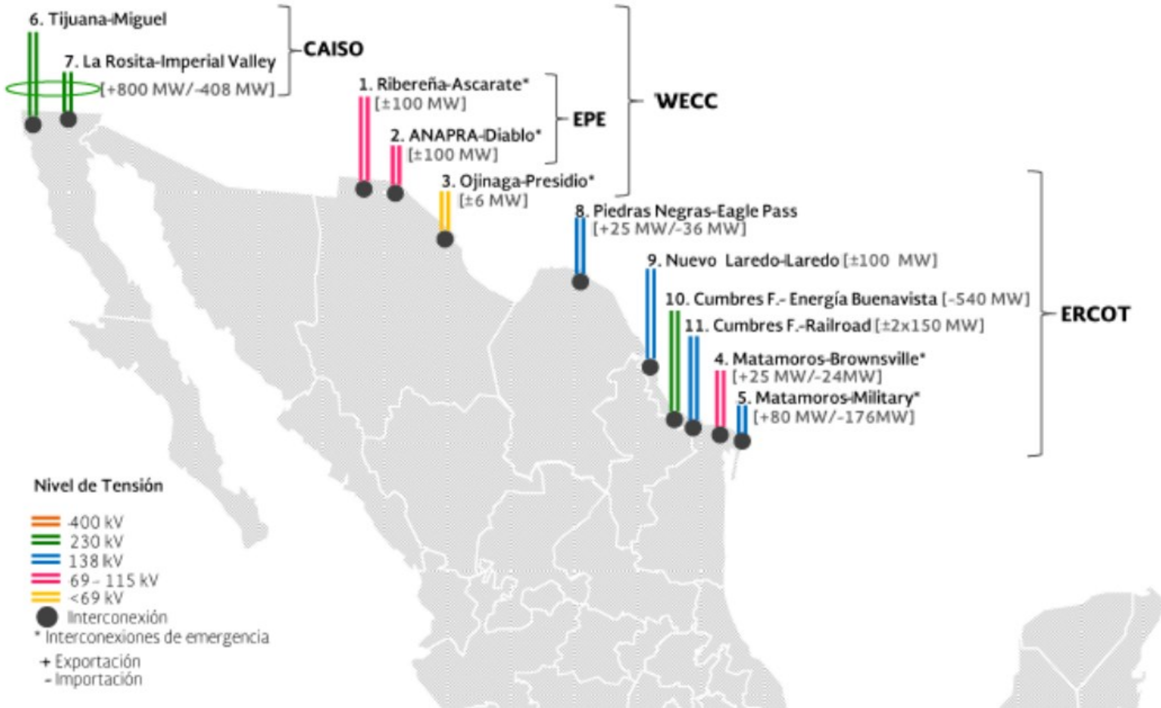


Figure 32: Mexico - United States Electricity Grid Interconnections (Source: (Fairley, 2017))

In addition to these existing interconnections with the United States, there are plans to develop a 600MW link between Mexico and California's Imperial Valley, as well as discussions about a high voltage direct current transmission line linking northern Baja California (Mexico) with the main Californian grid that would be capable of carrying thousands of Mega Watts of electricity (Fairley, 2017).

2.13 Myanmar

i. Renewable energy targets and trend

In 2016 Myanmar had modest ambitions to increase its wind and solar based electricity generation to 1.2% of total generation. More recently the economy has announced targets of 8% of electricity production from renewables by 2021 and 12% by 2025. However, aside from these targets, there are no specific legal frameworks or incentive mechanisms in the economy to support renewable energy development. While there are no specific incentives, electricity tariffs for consumers in Myanmar have been increased in order to increase the viability of pipeline power projects (Souche et al., 2019).

In terms of renewable energy installations, solar, wind and hydropower systems are being planned and constructed. There is only one current utility-scale solar project in Myanmar, which is the 170 MW solar power project in Minbu Township, Magwe Region. In addition to this development there is a 200 MW solar project planned for Meiktila Township and an additional 1.3GW worth of projects under discussion. With international financing there are also a number of small-scale off-grid solar projects being developed to support Myanmar's goals of increasing access to electricity (Souche et al., 2019).

Other than solar based renewable projects, Myanmar also has 32 existing small-scale[15] hydropower developments with a combined capacity of a little over 33MW (Saw and Ji-Qing, 2019), as well as a number of planned large-scale hydropower developments. Wind power developments have been lagging behind solar and hydropower, and currently there are no operational wind power projects in Myanmar, although in 2016 a memorandum of understanding was signed for a 30 MW wind power project and there are several project in feasibility study stages (Souche et al., 2019).

ii. Existing, planned and potential energy storage

Myanmar has a number of energy storage applications in the pipeline. For example, in November 2020 a Japanese company, 3DOM, signed an MoU to install a rooftop solar and battery storage system in the Pathein Industrial City project (3DOM, 2019). Also, as the majority of households in Myanmar do not have access to reliable electricity, there are efforts being made to install hybrid solar-diesel micro-grid generation systems that include energy storage (Kenning, 2019a).

iii. Existing, planned and potential pumped storage hydropower

Myanmar has no existing or planned PSH (Saw and Ji-Qing, 2019). Despite this, the economy has large PSH potential, with Blakers et al. (2021) concluding that there are over 13,000 potential PSH sites in the economy with a combined storage capacity potential of around 435,000GWh.

iv. Dispatchable power generation capacity and grid reliability issues

Grid reliability is not measured in Myanmar, however the economy is reported to have an unstable grid and aging infrastructure (Huang et al., 2019). As of 2017 around 39% of households in Myanmar had access to the electricity grid and the economy has a goal of increasing this percentage to 100% of households with an electricity supply by 2030, including both on-grid and off-grid connection (Souche et al., 2019).

Myanmar's installed electricity generating capacity grew by 2.2GW between 2010 and 2018, reaching an installed capacity of 5.65GW in 2018 (Figure 33).

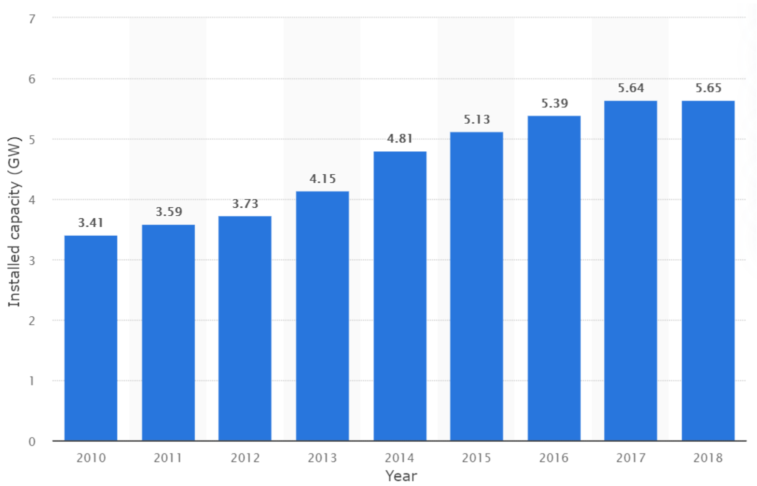


Figure 33: Myanmar's installed electricity generating capacity (2010 - 2018) (Source: (Moore, 2020))

15 Small-scale hydropower refers to systems with an installed capacity of 10 MW or less.

v. Cross-border electricity transmission grids

The ASEAN Master Plan on Connectivity (2011) included a planned grid connection between Myanmar and Thailand. The ADB (2019) also reports a low voltage (34.5/22 kV) transmission link between northern Lao PDR and Myanmar (see Figure 28 on page 52).

2.14 New Zealand

i. Renewable energy targets and trend

Historically, New Zealand, for reasons associated with environmentally benign use of natural resources, has relied very heavily on hydropower. In the 1960s New Zealand pioneered the use of large-scale geothermal, and began adding some fossil fuel-based generation elements from 1958 in order to manage hydropower constraints during dry periods. This was largely because in New Zealand it has, and continues to be considered environmentally unacceptable to construct the large-scale reservoirs required for long-term hydropower water storage (Philpott et al., 2019).

Between 1975 and 2017 the share of New Zealand's electricity generation coming from renewables, including hydropower, has varied between around 90% (1980) and about 65% (2006). Since 2006 there has been a reasonably steady rise in the share of renewable based generation, reaching around 83% in 2017 (Figure 34).

In 2011 the government of New Zealand published its *National Policy Statement for Renewable Electricity Generation*, with a target of 90% of electricity generation coming from renewable sources by 2025 (GoNZ, 2011). In the lead up to New Zealand's elections in October 2020, the ruling labour party has announced that, if they win government, they will phase out all non-renewable electricity generation by 2030, moving the existing target forward by five years (Good News Network, 2020).

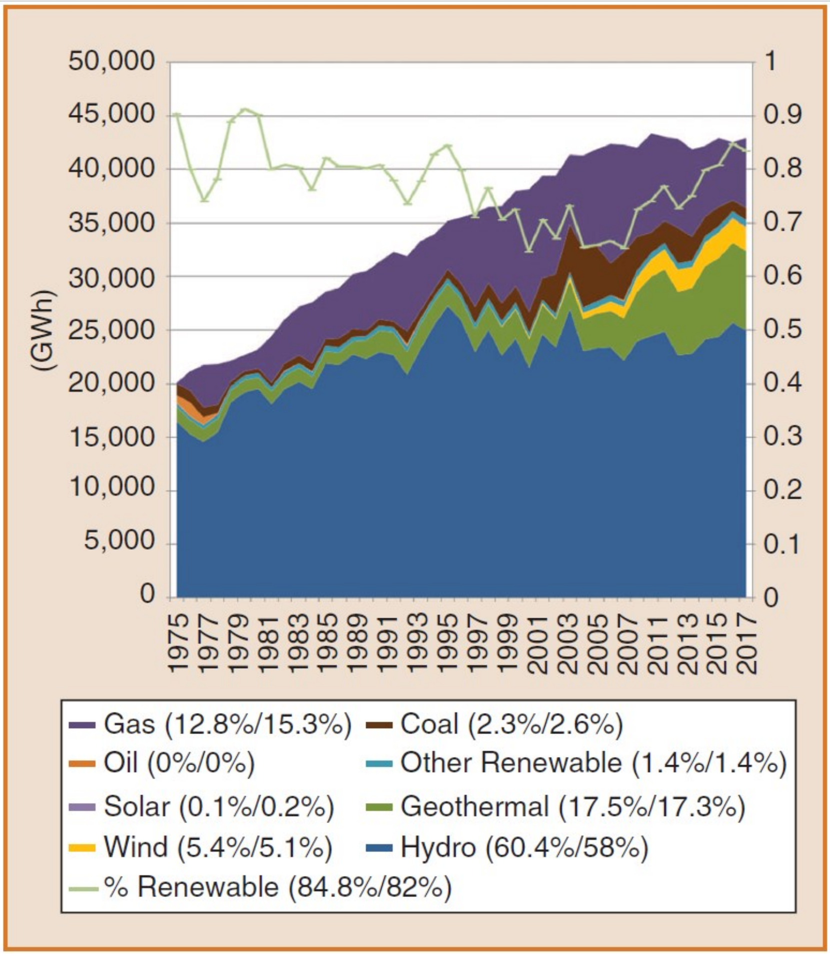


Figure 34: Generation by type in New Zealand (1975 - 2017) Source: (Philpott et al., 2019)

Note: The numbers beside each generation type in the legend show proportion of generation in 2016/proportion of generation in 2017

ii. Existing, planned and potential energy storage

In 2018, New Zealand's first grid–scale battery storage facility was commissioned in Auckland. This battery can supply power at a rate of 1MW and store 2MWh of electricity (McQueen, 2019; Tong et al., 2019). Despite this, at the utility scale, batteries do not seem likely to have a large role in ensuring New Zealand's energy security in the near future. This is only likely to change when solar and/or wind generation outputs becomes so high that there is no longer any capacity to back of the hydropower generation, and energy must be spilt. There is some scope for residential use of batteries, however the uptake of this will depend on reduced cost of batteries (Philpott et al., 2019).

iii. Existing, planned and potential pumped storage hydropower

PSH was considered in New Zealand in 2013, however it was considered not to be economical at that time, and that it was unlikely that any PSH would be constructed prior to 2025 (Kear and Chapman, 2013). Since then, only four PSH sites have been identified.

Potential PSH systems that have been studied (McQueen, 2019):

1. Lake Onslow, fed by water from the Clutha River, with a 650m head;
2. Linking lakes Hawae and Wanaka (although the mixing of waters between the two may contravene Kaitiakitanga, an environmental management process based on the Maori world view);

3. A scheme to generate 100% renewable electricity for Oban, a remote community on New Zealand's Stewart Island;
4. The possibility of using the Southern Alps valleys in the Canterbury region, with Lake Pukaki or Lake Tekapo as the lower reservoir.

McQueen (2019) assessed potential for PSH in New Zealand, dividing each of open and closed loop PSH systems into two variants, as per Table 15.

Table 15: PHS types as defined by McQueen (2019)

PSH Type	Open or Closed Loop	Description
1	Open Loop	Use existing reservoirs (upper and lower)
2		An upper reservoir constructed above an existing water body
3	Closed Loop	Refurbish abandoned mine pits or other brown-fields sites as reservoirs
4		Off river schemes (e.g. construction or both upper and lower reservoirs)

McQueen (2019) notes that assessing potential type 1 PSH sites is a simple matter, but that for the other 3 types the task is complex, and requires significant engineering optimisation, geographical analysis and location specific knowledge. For type 1 PSH systems, McQueen used four criteria to assess PSH potential: (i) Reservoirs were not in, or bordering, conservation department land, (ii) Energy storage had to be a minimum of 100MWh, (iii) Minimum elevation difference between the two reservoirs of 50m, and (iv) The head to length ratio had to be more than 0.66. Using these criteria McQueen (2019) found a total of ten possible sites with a combined total energy storage of 36.1GWh. He notes that potential for PSH types 2, 3 and 4 is far greater, but because the analytical complexities a detailed assessment is not included in his paper.

Modelling done by Blakers et al. (2021) shows that New Zealand has the potential to store around 40,000GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

New Zealand has a reliable grid that is underpinned by the major hydropower generation centres shown in Figure 35.

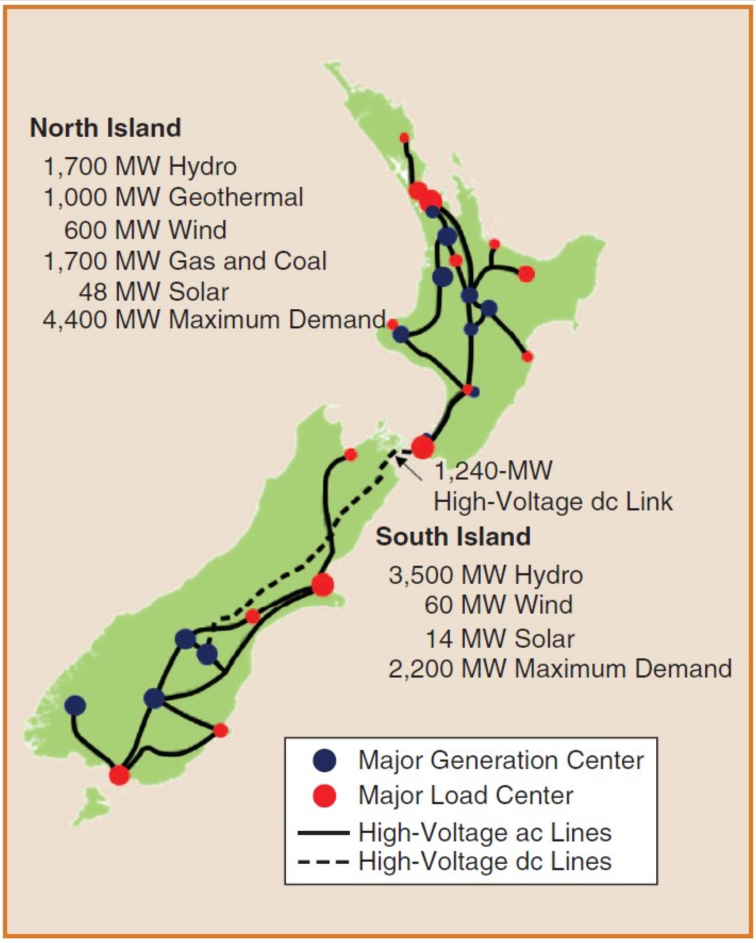


Figure 35: New Zealand's main generators, transmission lines, and maximum loads in 2017 (Source: (Philpott et al., 2019))

The economy experiences few shortages or wide-spread power outages. However, the reliance on hydropower for generation does create the risk of energy shortage in dry years (e.g. 1992) (McQueen, 2019). This risk is amplified because New Zealand's largest electricity demand is in mid-winter, when rainfall is the lowest (Philpott et al., 2019).

v. Cross-border electricity transmission grids

As a economy geographically separated from its nearest neighbours by ocean, New Zealand has no cross-border electricity grids (Philpott et al., 2019)

2.15 Papua New Guinea

i. Renewable energy targets and trend

In 2016, Papua New Guinea published its Nationally Determined Contribution (NDC) in line with the Paris Agreement.[16] Their NDC included a target of 100% of electricity sourced from renewable generation sources by 2030, with a strong reliance on external funding and the private sector required to achieve this (Lim, 2017; Senshaw and Kim, 2018).

[16] The Paris Agreement builds on the United Nations Framework Convention on Climate Change (UNFCCC), bringing economies together to ambitiously combat climate change as well as to adapt to climate change impacts. The agreement also includes increases in support for developing economies achieve the Paris Agreement goals (United Nations: Climate Change, 2020).

In the last decade Papua New Guinea has installed approximately 100MW of additional generating capacity, and in 2018, 25% of Papua New Guinea's electricity was sourced from hydropower (Weir, 2018), 66% was from fossil fuel based generation, and the remainder from other renewables (Figure 36).

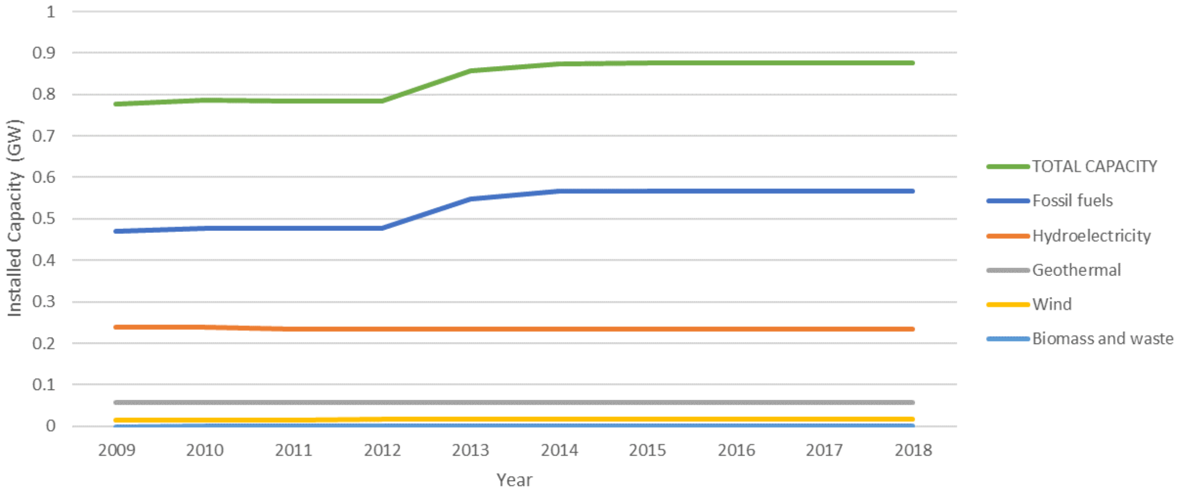


Figure 36: Installed electricity generating capacity in Papua New Guinea (2009 - 2018) (Data sourced from (USEIA, 2020))

Of Papua New Guinea's nearly 900MW of installed generating capacity, 280MW is generated and consumed by mining companies (ADB, 2017).

ii. Existing, planned and potential energy storage

Searches of the literature and government documents do not show any existing, planned or announced energy storage in Papua New Guinea. However, modelling done by Blakers et al. (2021) shows that the economy has the potential to store around 392,000GWh of electricity in PSH systems.

iii. Existing, planned and potential pumped storage hydropower

Papua New Guinea has not installed, planned or announced PSH (IHA, 2020c; USEIA, 2020). Despite this, there is large potential for PSH in Papua New Guinea (Figure 37).

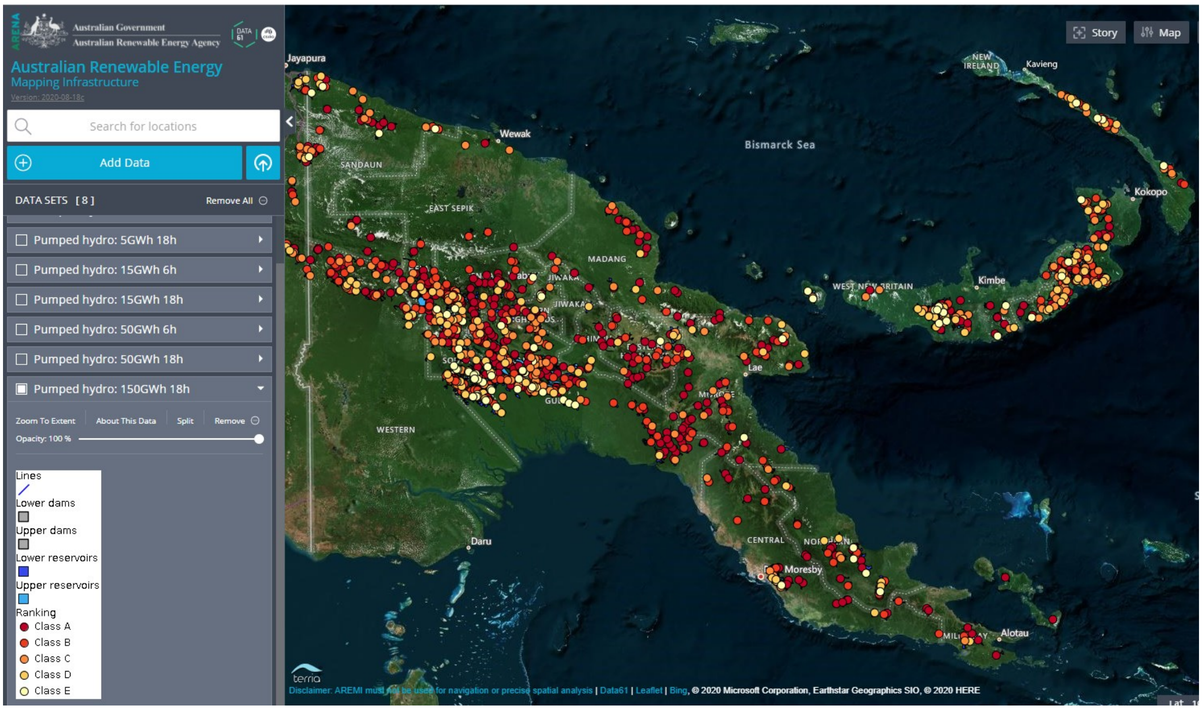


Figure 37: PSH potential in Papua New Guinea with storage of 150GWh or greater (Source: https://nationalmap.gov.au/renewables/#share=s-oDPMo1jDBBtwBNhD)

iv. Dispatchable power generation capacity and grid reliability issues

Papua New Guinea's electricity grid requires efforts to increase its reliability, with customers on average facing power outages 116 times a year with a total time without power of over 200 hours per customer across these events. The economy also has low rates of electrification, with 75% of the population without access to the electricity grid (Sandu et al., 2020). As published in Papua New Guinea's Development Strategic Plan 2010-2030, the economy has a goal of 70% of the population with access to electricity by 2030 (ADB, 2017; Rawali et al., 2019).

v. Cross-border electricity transmission grids

Papua New Guinea has approximately 4% grid penetration into Papua New Guinean rural areas (Sakato et al., 2019), and there is no evidence of cross-border grid connections.

2.16 People's Republic of China

i. Renewable energy targets and trend

From 2008, there has been strong growth in the renewables sector in China. This growth has been supported by the 2005 Renewable Energy Law (amended in 2009) (Liu, 2019). For example, installed solar capacity on average more than doubled each year over the period 2008 to 2017, and installed wind-based generation doubled every three years over the same period. By the end of 2017 China's renewable generation capacity, excluding hydropower, was 294GW (or 16.5% of the total generating capacity of 1,778GW). Hydropower accounted for about 19% of total generating capacity in China at the end of 2017, with installed capacity of 341GW (Liu, 2019). By 2019, renewables generation had grown to 415GW, accounting for 21% of installed capacity (Table 16).

China established a renewable energy portfolio standard (RPS) in May 2019. The RPS is used to set renewable energy targets each year for every Chinese province, and the provinces are responsible for designing implementation details such as tracking and enforcement mechanisms. The RPS focuses on wholesale electricity purchasers, grid companies and owners of power plants, with each of these entities obliged to contribute towards the renewable energy target for the province (Yuan and Riley, 2020). Nationally, the initial RPS target is to achieve 35% of electricity generation from renewable sources[17] and 20% of total primary energy consumption by 2030 (Patel, 2018; Sharma, 2019).

ii. Existing, planned and potential energy storage

China has been expanding its battery storage for electricity since 2010, with battery storage reaching almost 1.1GW in 2018 (Figure 38).

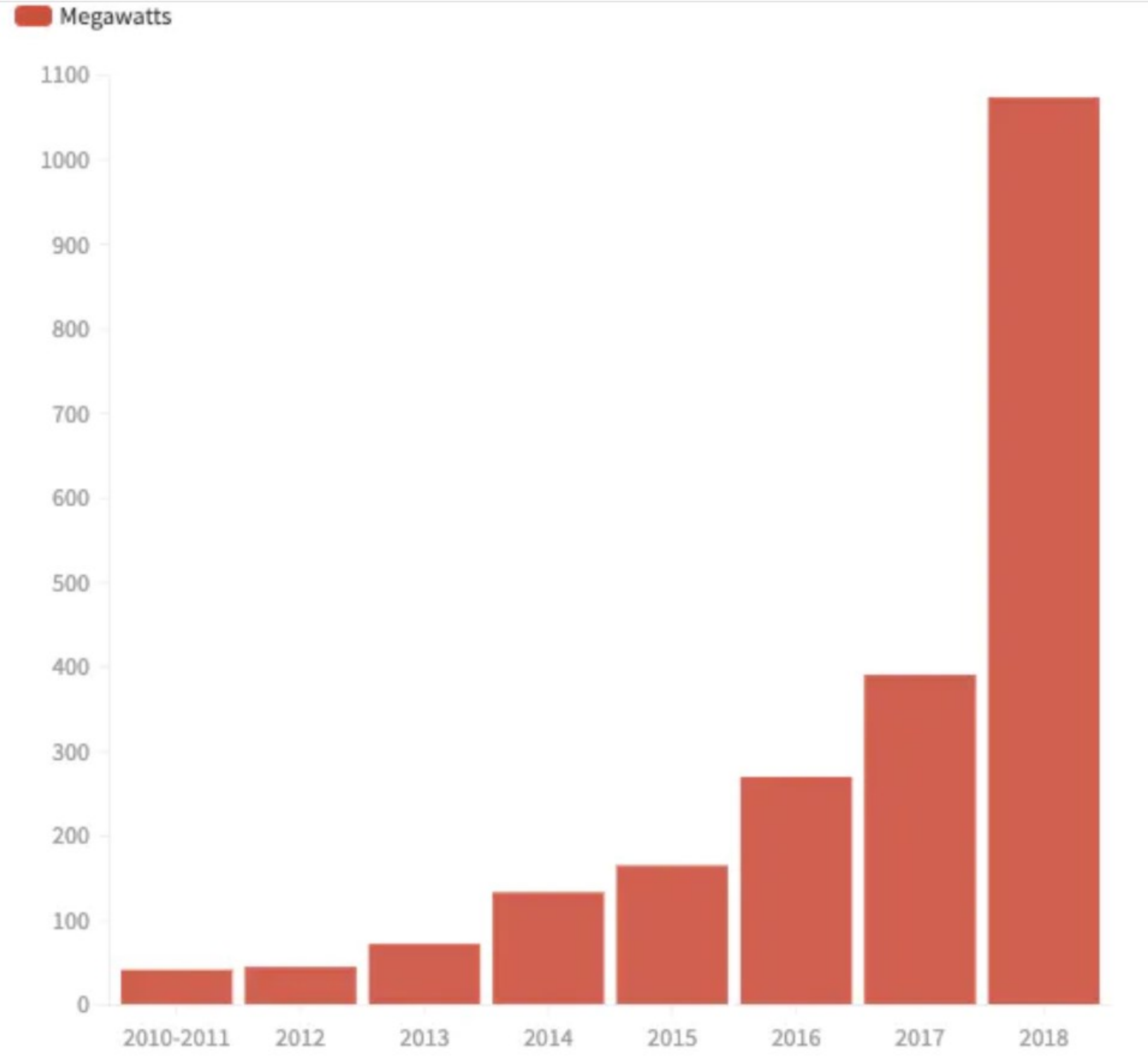


Figure 38: China's installed battery storage capacity (2010 - 2018) (Source: (Schoenmakers and Chinadialogue, 2020))

iii. Existing, planned and potential pumped storage hydropower

China is the world leader in PSH, with a current total of 30GW of installed PSH (Sailer, 2020), however a pause on new PSH systems has meant that during 2019 installation of PSH growth slowed with 300MW installed in 2019, compared with planned installation of 2GW (IHA, 2020a). China's projected

[17] It is not clear whether this target includes hydropower or not

growth of PSH is driving PSH growth globally, with an additional 45GW of PSH projected to be installed in China by 2030 (Figure 39).

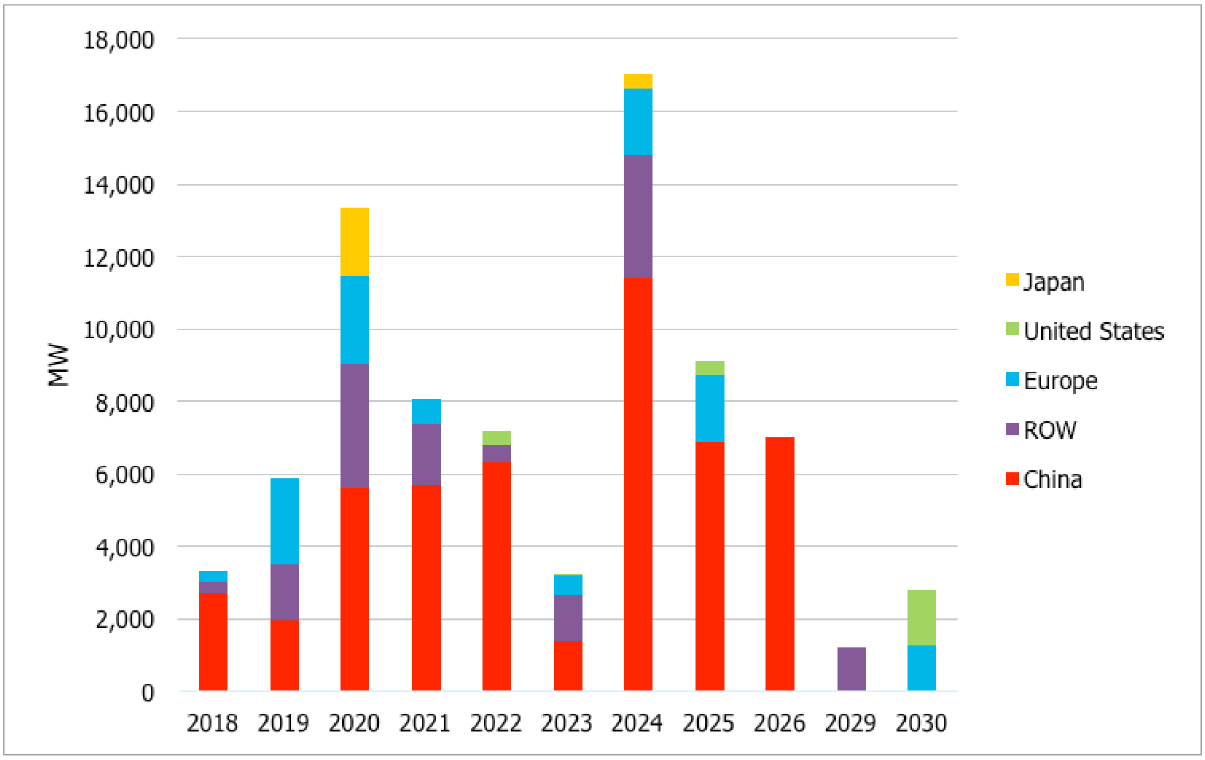


Figure 39: Projected growth in PSH around the world (Source: (IHA, 2020a))

In addition to China's existing and planned PSH, modelling done by Blakers et al. (2021) indicate that China has the potential to store over 3.5 Million GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

China's total power generation capacity in 2019 was 2,011GW, which included 415GW of installed wind and solar generating capacity (Table 16).

Table 16: China's generating capacity (2018 & 2019) by generator type (Source: (CEP, 2019))

Generator Type	2018 (GW)	2019 (GW)	Growth (%)
Hydro power	353	356	1.1
Thermal power	1,144	1,191	4.1
Nuclear power	45	49	9.1
Wind power	184	210	14
Solar power	174	205	17.4
TOTAL	**1,900**	**2,011**	**5.8**

There is no evidence in the literature of grid reliability issues in China, however there are projects being implemented to enhance grid reliability in some parts of the economy (e.g. ABB, 2018).

v. Cross-border electricity transmission grids

China has transmission lines linking to Hong Kong, China, Myanmar, Lao PDR, Viet Nam, and Russia. There are also links being considered with Thailand, Pakistan, Bangladesh and Mongolia (HK-Phy, 2003; Josefson et al., 2019; Okutsu et al., 2020).

2.17 Peru

i. Renewable energy targets and trend

In 2008, Peru implemented its Legislative Decree 1002 on investment promotion for generation of electricity using renewable energy. This decree had a focus on increasing renewable generation (not including hydropower plants larger than 20MW). It included a target of 5% of total generation to be from renewables by 2013, and it directed the Ministry of Mines and Energy to develop plans for renewable energy deployment on a five yearly basis and to establish a enewable energy plan for the economy (IEA and IRENA, 2017).

Peru's main pieces of legislation relating to renewable energy targets are shown in Table 17.

Table 17: Peru's main renewables related energy policies (Source: (IEA and IRENA, 2017))

Policy	Year	Summary
Legislative Decree 1002 on investment promotion for generation of electricity using renewable energy of Peru	2008	Focus on renewables other than hydropower over 20MW, required development of an economy-wide renewable energy plan, and included a target of 5% of electricity generated from renewables by 2013.
Peru Renewable Energy Auctions	2009	Building on decree 1002, Peru has held annual renewable energy auctions since 2009 for both grid-connected and off-grid renewable energy generation
Compliance of the Renewable Energy Resources Electricity Generation Agreement	2009	This regulation regulates bid and construction guarantees for who successfully bid and signed renewable energy contracts
National Energy Plan for 2010-2040	2010	Provides the legal framework for energy in Peru, with four primary objectives: 1. promote environmentally sustainable energy development 2. Ensure compatibility with the member's environment policy 3. Promote use of solid and liquid waste for energy generation 4. Encourage constructive relationships between the state, companies, and communities in the energy sector
New Regulations of Electricity Generation from Renewable Energy	2011	This regulation amends decree 1002, with new conditions for the commercialisation, cost evaluation and sale of renewably produced energy
2013-2022 National Rural Electrification Plan of Peru	2012	Requires project selection to consider renewable energy as a criterion when selecting projects (weighting of 10% for evaluation) Has a planned investment of USD$1,280 million in rural electrification over 2013-2022, including USD$390 million in renewable generation (including criterion hydropower under 20MW)

Policy	Year	Summary
National Photovoltaic Household Electrification Program	2013	Target of 500,000 households with solar PV systems installed by 2016 (progress unknown)

Over the period 2006 – 2010, Peru's renewable generation share, including hydropower, was about 63.5%, however this declined to about 54% over the period 2011 – 2015 as the proportion of natural gas in the electricity generation portfolio increased (IEA, 2020d; Washburn and Pablo-Romero, 2019).

Since 2000, Peru's energy mix has followed the trends shown in Figure 40.

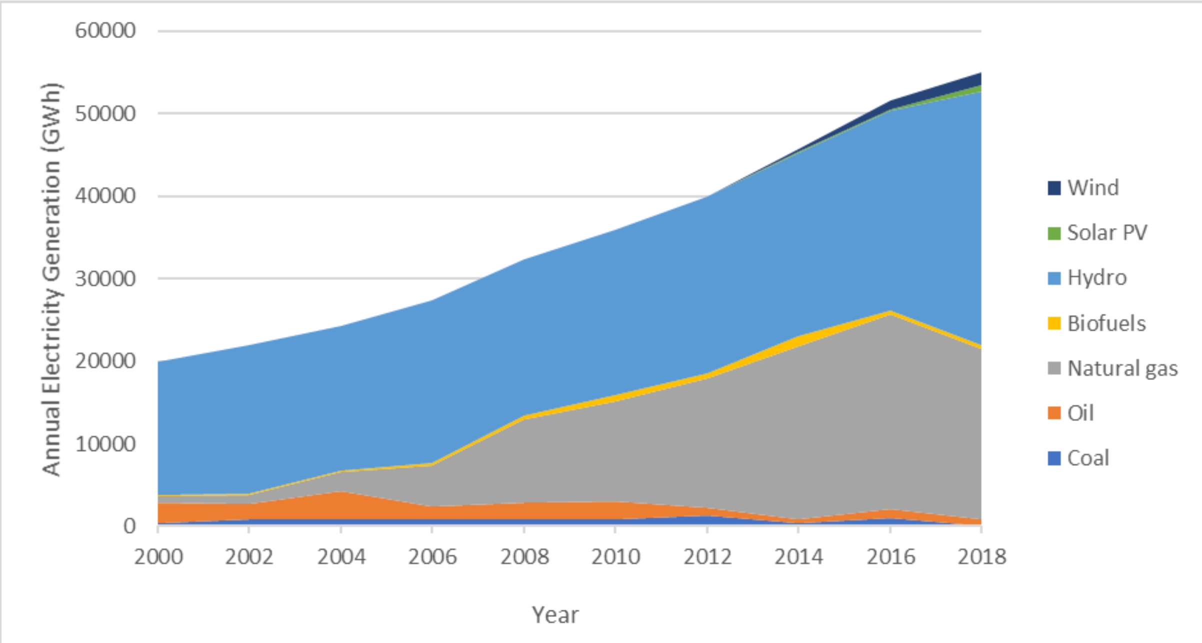


Figure 40: Energy mix trends in Peru (2000 - 2018) (Source: Data sourced from (IEA, 2020d))

As shown in Figure 40, natural gas and hydropower dominate the electricity generation sector in Peru, with combined generation accounting for more about 93% of total generation in 2018 (IEA, 2020d).

ii. Existing, planned and potential energy storage

Searches of the literature, of government policy documents and the internet more generally do not indicate any existing or planned electrical energy storage in Peru. There are a number of articles in the literature that explore opportunities for the mining industry to use renewable generation plus storage, and for remote communities to use remote area power supplies including storage capacity (e.g. Bazán et al., 2018; Haas et al., 2020).

iii. Existing, planned and potential pumped storage hydropower

A search of the literature, lists of PSH systems (e.g. IHA, 2020c), and of the world wide web more generally does not return any examples of existing, planned or potential PSH in Peru. Despite this, the mountainous terrain of Peru suggests there are opportunities to use PSH as a storage system in Peru, and modelling done by Blakers et al. (2021) shows PSH-based electricity storage potential of around 553,000GWh.

iv. Dispatchable power generation capacity and grid reliability issues

Peru's electricity grid has three main areas: the southern, central and northern zones. The grid includes a 500kV line connecting the northern and southern zones, as well as 220kV lines connecting the central zone with each of the northern and southern zones (Clarke et al., 2018) (see also Figure 41).

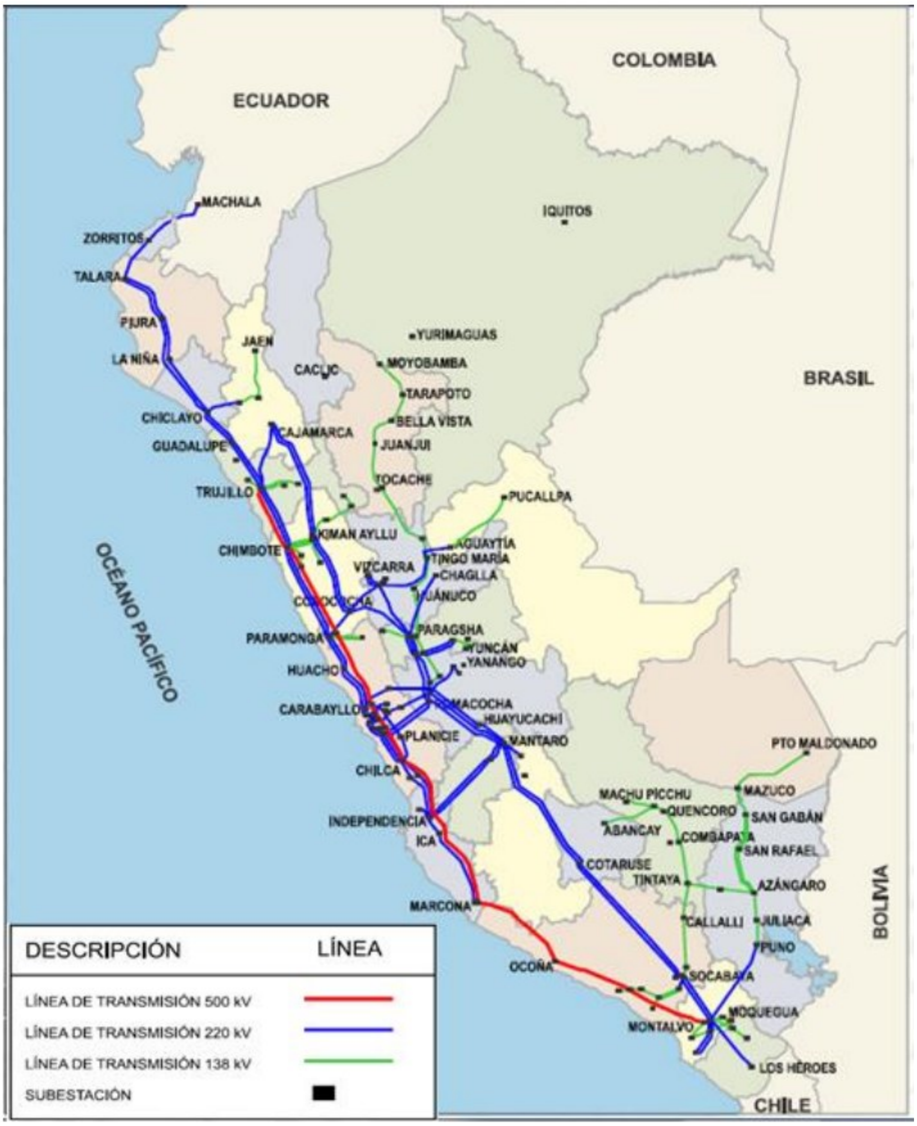


Figure 41: Main components of Peru's electricity grid (Source: (Clarke et al., 2018))

v. Cross-border electricity transmission grids

Peru has one cross-border transmission line, which is a 220 kV transmission line connecting the Peruvian grid with Ecuador (Clarke et al., 2018).

2.18 Republic of Korea

i. Renewable energy targets and trend

In 2019, the proportion of energy sourced from renewables in the Republic of Korea (ROK) was less than 5% of total generation, including hydropower (Park and Kim, 2019). The government has a goal of increasing this proportion to 20% of electricity generated from renewable sources by 2030[18] (Hong et al., 2019), up from the 9.7% target included in the ROK's 2014 basic plan (Table 18).

Table 18: The ROK's 4th Basic Plan Renewable Energy Generation Targets (2014) (Source: (In-Ha, 2014))

	2020	2025	2030	2035
Renewable targets as percentage TPES*	5	7.7	9.7	11

* *TPES = Total Primary Energy Supply*

However there are a number of challenges to achieving this goal: (i) the ROK has a very energy intensive economy, built on manufacturing for export, (ii) the government does not have concrete action plans detailing how the 2030 goal will be achieved, and (iii) a social consensus has not been reached regarding the transition to renewables (Hong et al., 2019). A common argument in the Republic of Korea (ROK) against renewable generation of electricity builds on concerns about supply of baseload power (Park and Kim, 2019).

Figure 42 shows a renewable energy policy timeline for the ROK as well as trends in the proportion of electricity generation from renewables.

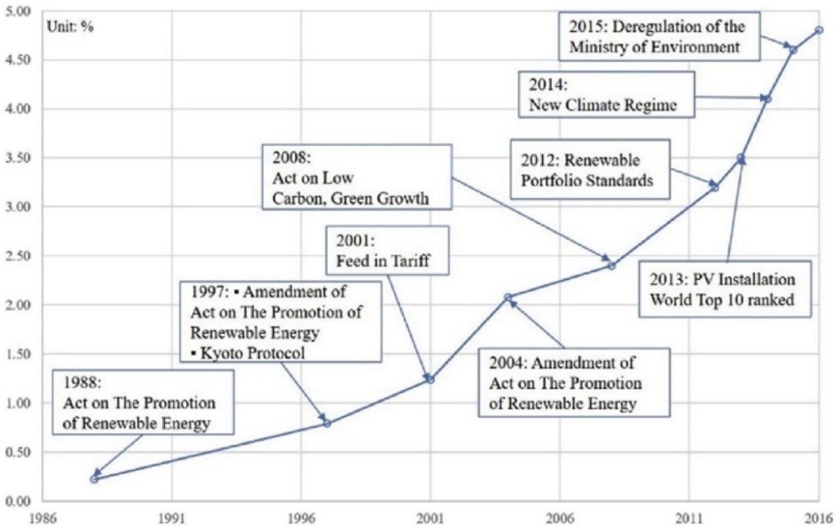


Figure 42: ROK: Energy Policy and renewables share of power generation (1988 - 2016) (Source: (Park and Kim, 2019))

ii. Existing, planned and potential energy storage

Energy storage does not appear to be a major consideration in the ROK, although there have been some studies done on the economics of electrical storage systems for utilities (e.g. Kim et al., 2019).

iii. Existing, planned and potential pumped storage hydropower

The ROK has 4.7GW of installed PSH capacity (IHA, 2020a; Sailer, 2020).

Modelling done by Blakers et al. (2021) shows that ROK has the potential to store around 36,000GWh of electricity in PSH systems.

[18] The target of 20% from renewables was broken down to include 37 GW of PV generation, 3 GW of onshore wind generation, and 13 GW of offshore wind generation (Park and Kim, 2019).

iv. Dispatchable power generation capacity and grid reliability issues

The ROK electricity grid, showing major generator locations and transmission lines is shown in Figure 43.

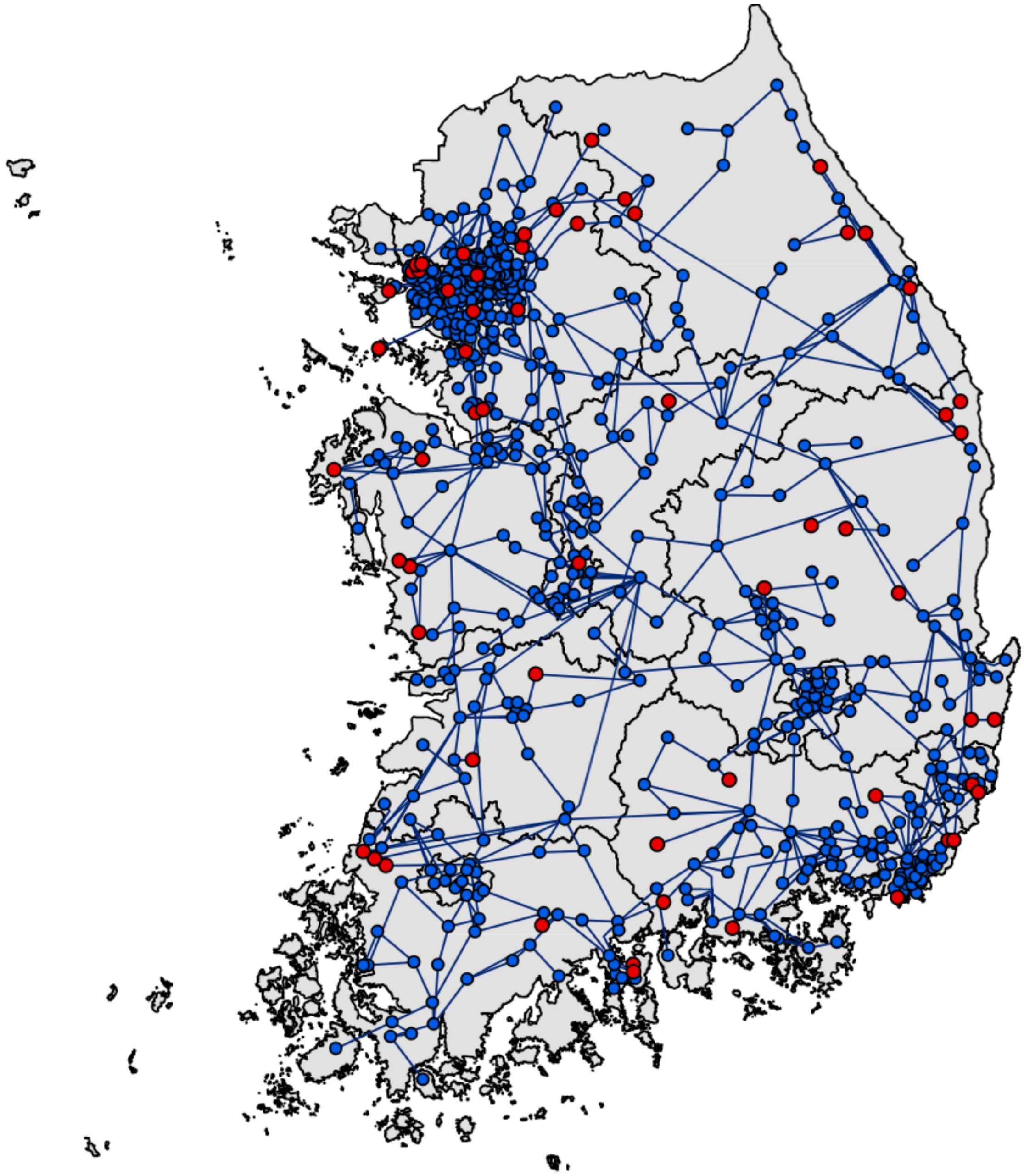


Figure 43: Main components of the ROK electricity grid (red dots indicate generators, and blue dots indicate substations) (Source: (Eisenberg et al., 2017))

The ROK's electricity generating capacity grew by more than 60% over the period 2008 – 2018, to a total generating capacity of 119GW (Figure 44).

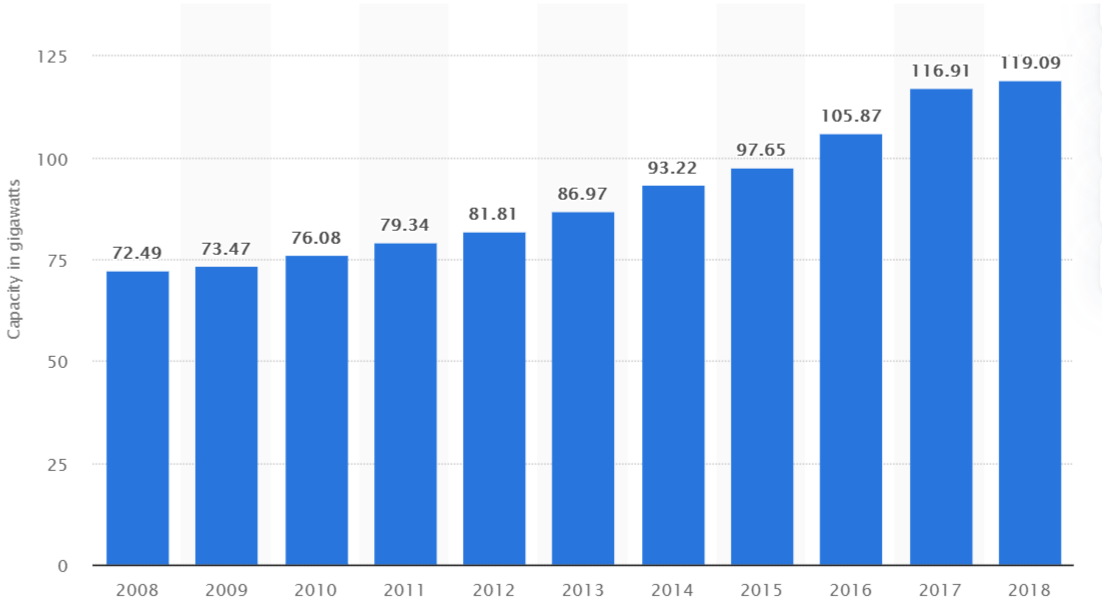


Figure 44: Trend in electricity generation in the ROK (2008 - 2018) (Source: https://www.statista.com/statistics/990708/south-korea-installed-electricity-generation-capacity/)

The ROK has one of the most reliable electricity grids in the world (Statista, 2020b).

v. Cross-border electricity transmission grids

The ROK is located on the southern section of the Korean peninsula, with the economy's only land border being with the Democratic People's Republic of Korea (with the two economies still separated by a demilitarised zone). As such, the ROK does not have any cross-border electricity grids (Bae and Lee, 2018). There are plans to build a high voltage direct current (HVDC) submarine link between China and the ROK (Turner, 2020).

2.19 Russia

i. Renewable energy targets and trend

In 2009 Russia adopted a target of 4.5% of electricity production to be from renewables by 2020.[19] However by 2011 the economy had missed its first interim milestone of 1.5% renewable power generation by 2010, and the economy's Energy Forecasting Agency was suggesting that the 4.5% target may be reached by 2030 (IFC, 2011). Part of the reason that the 2010 milestone was missed was that it was not until 2013 that a support mechanism for the renewables wholesale market was introduced (Kozlova et al., 2020). Further, when a support scheme for retail renewables was introduced, it devolved responsibility for implementing support measures to regional authorities, who were reluctant to develop the necessary regulatory frameworks and prepare contracts (Kozlova et al., 2020).

Installed renewable energy generation in 2020 in Russia was about 3GW, with an additional 7GW planned for construction up to 2024 (Kozlova et al., 2020). As of 2015, around 20% of Russia's power generation (53.5GW) was from hydropower, including 1.2GW of planned PSH (IRENA, 2017). Excluding

[19] The 4.5% target came under Government resolution No. 1-r "On Main Directions of State Policy in the Sphere of Increase of Energy Efficiency of Electric Power Generated On the Basis of Renewable Energy Sources for the Period Until 2020" dated 8 January 2009 (Josefson et al., 2019).

large-scale hydropower, the renewable generation sector in Russia is made up of about 60% biomass, 25% small-scale hydropower and 15% from solar and wind generator (Josefson et al., 2019).

ii. Existing, planned and potential energy storage

There are a number of electrical energy storage projects in the pipeline in Russia. For example, the Hevel Group has been contracted to construct a solar plus storage (10MW PV plant plus 8MWh Li-ion battery) in Russia's Burzyan District (Kenning, 2019b)

iii. Existing, planned and potential pumped storage hydropower

Russia's Zagorsk pumped-hydro storage plant was approved in the 1970s, with the first turbines installed in 1987. The plant has an operating installed capacity of 1,200MW (IRENA, 2017). A second, smaller scale, open loop pumped-hydro storage project (140MW) was constructed in Karachay-Cherkessia, the (IRENA, 2017).

While no evidence of plans to construct additional PSH in Russia was located, Blakers et al. (2021) have assessed that the economy has the potential to store around 20,000GWh of electricity in PSH systems.

iv. Dispatchable power generation capacity and grid reliability issues

Russia's electricity generating capacity is the fourth largest in the world, with a total capacity of 243GW. This is made up as per Table 19.

Table 19: Breakdown of generator types and market share in Russia (Source: (Josefson et al., 2019))

Generator type	Percentage of total (%)	Generating Capacity (GW)
Natural Gas	47.6	115.6
Coal	18.4	44.8
Liquid and other	1	2.4
Hydropower	20	48.6
Nuclear	12	29.2
Other	1	2.4
TOTAL	**100**	**243**

The major owner of grid infrastructure in Russia is the state-owned Russian Grids Public Joint Stock Company (PJSC). This company manages 507,000 substations and 2.3 million kilometres of transmission lines. Around 70% of the Russia's population receives electricity via Russian Grids PJSC (Josefson et al., 2019).

Russia's electricity grid has seven territorial divisions: Northwest, Centre, South, Middle, Volga, Ural, Siberia and Far East (Figure 45).

Figure 45: Russia's electrical grid regions (Source: (Sánchez-Ortiz, 2019))

The Siberia and Far East regions together host about 13% of Russia's population and are underserved by grid infrastructure (Sánchez-Ortiz, 2019).

Because of aging distribution infrastructure, up to 30% of grid connection applications are denied in larger Russian cities (Ferris, 2014).

v. Cross-border electricity transmission grids

Russia imports electricity from Kazakhstan (approximately 95% of imports), as well as from the other Commonwealth of Independent States (CIS) economies.[20] In addition to imports, Russia also exports electricity to economies including Finland, Belarus, Lithuania, Georgia, Azerbaijan, Kazakhstan, China and Mongolia (Josefson et al., 2019).

2.20 Singapore

i. Renewable energy targets and trend

The Singaporean government notes that most renewable energy sources are not compatible with the geography and circumstances of the island state (NCCS, 2020a). In particularly it notes that:

- average wind speeds are too low for development of commercial wind farms,
- a lack of fast flowing rivers means hydropower is not a viable option,
- the economy's small land area and high population density limit possibilities for use of biomass, and
- Singapore has no geothermal energy sources.

[20] The 12 CIS economies are: Russia, Ukraine, Belarus, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Armenia, Azerbaijan, and Georgia, and Moldova (The Editors of Encyclopaedia Britannica, 2018).

Singapore does have high solar irradiation potential. Despite this, the government is cautious about the potential for this to contribute significantly, particularly in terms of provision of baseload power (NCCS, 2020a). Singapore does have energy efficiency targets though, and has established strategies to expand the use of solar PV arrays. The economy's SolarNova programme was launched in 2014. This programme is being led by the Economic Development Board and the Housing Development Board in order to accelerate installation of PV systems. The SolarNova programme has a goal of contributing 220MW of installed PV capacity on Housing Development Board apartment buildings by 2020 (HDB (Singapore), 2019). This will form a part of Singapore's target of 350MW of installed renewable energy by 2020 (Erdiwansyah et al., 2019b), and solar PV arrays should generate around 8% of peak electricity demand by 2030 (NCCS, 2020a), which will be equivalent to about 2GW of installed solar PV capacity (Bhambhani, 2019; EMA (Singapore), 2020).

Recent growth in installed solar PV in Singapore is shown in Figure 46.

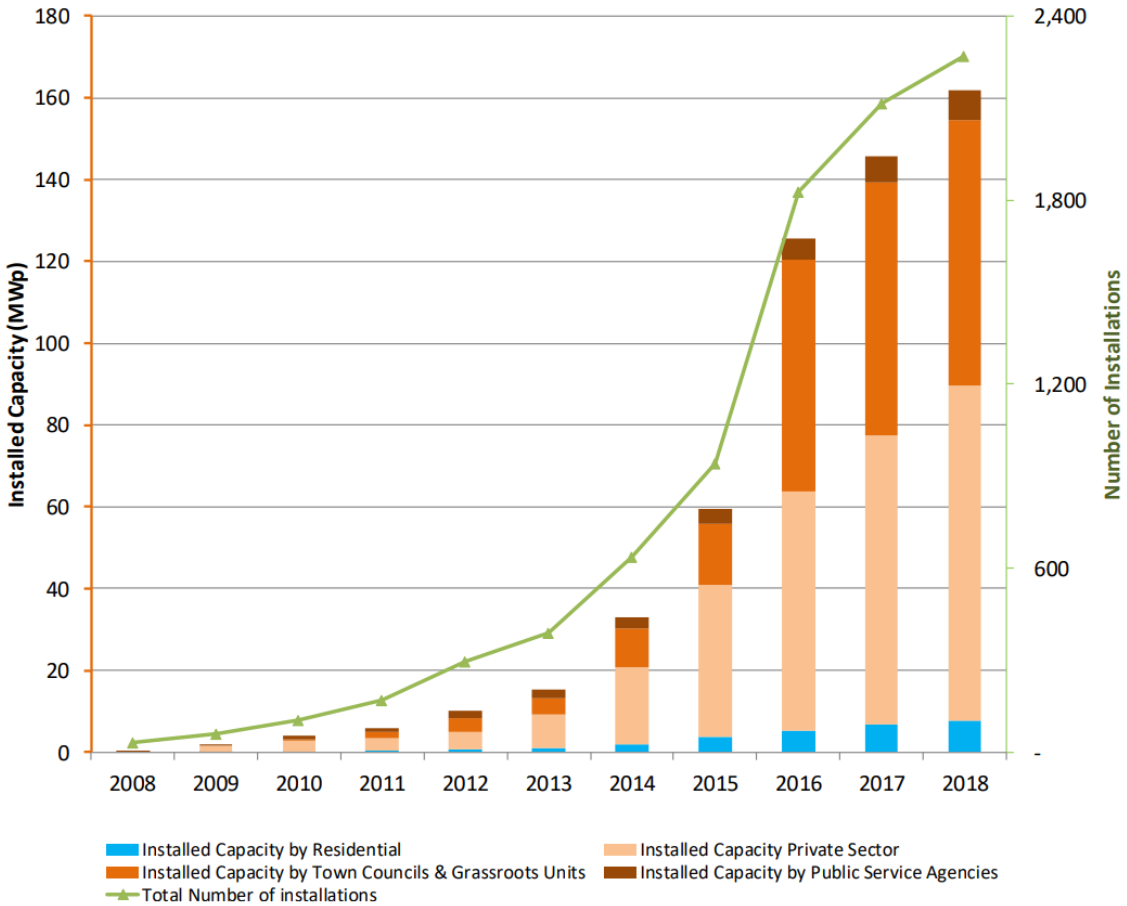


Figure 46: A decade of Solar PV installed capacity growth in Singapore (2008 - 2018) (Source: (EMA (Singapore), 2018))

In 2017 Singapore committed to implementing a carbon tax from 2019 (Figure 47), which may encourage further investment in renewable energy systems.

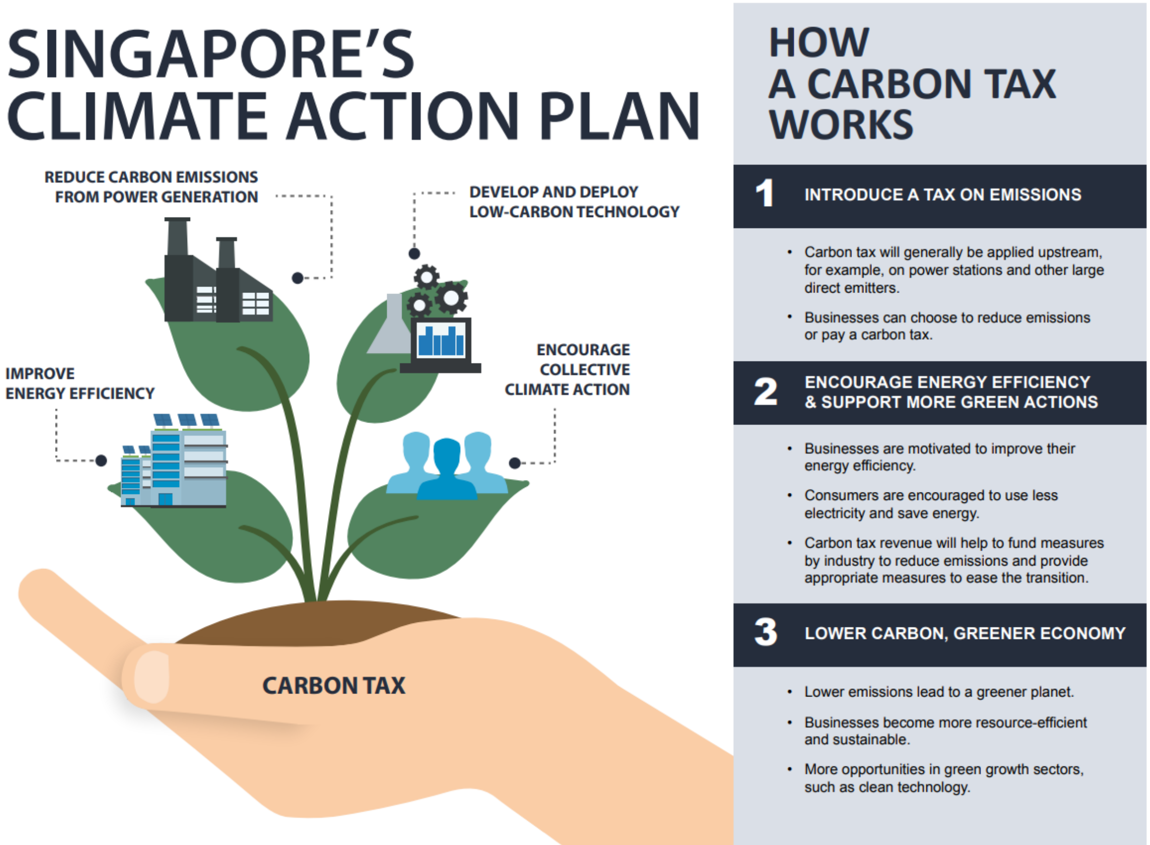


Figure 47: Singapore's use of a carbon tax as part of its mitigation strategy for greenhouse gases (Source: (NCCS, 2020b))

ii. Existing, planned and potential energy storage

In October 2017, Singapore's Energy Management Authority (EMA) and Singapore Power awarded SD$17.8 million to implement Singapore first utility-scale ESS, which used flow batteries and chemical battery storage (EMA (Singapore), 2018). The EMA recognises the potential for conflict of interest if the grid operator is the owner and operator of ESS assets for grid applications, and will seek to implement measures to safeguard consumers' interest by addressing any conflicts of interest. This is likely to include measures to ensure the most-cost ESS effective solution is procured, and that ESS capacity is appropriately sized. ESS solutions in Singapore are likely to include electric vehicle "vehicle-to-grid" arrangements (EMA (Singapore), 2018).

In 2020, Singapore announced an agreement to construct a floating 7.5MW lithium-ion battery as a test-bed for battery electrical energy storage (Hellenic Shipping News, 2020).

In addition to energy storage systems under development, Singapore has plans to build 200MW of electrical energy storage to support the goal of 2GW of installed PV capacity by 2030 (Bhambhani, 2019).

iii. Existing, planned and potential pumped storage hydropower

There have been calls in the Singapore media for underground PSH to be used as a low-carbon energy storage option (Tim, 2015). Despite this, however, the Singaporean government has not published any plans or strategies to pursue PSH. To the contrary, government websites note that hydropower is not a viable option in Singapore (NCCS, 2020a).

iv. Dispatchable power generation capacity and grid reliability issues

Singapore's capacity has grown by about 40% since 2005, to reach a total generation capacity of 13.7GW in 2019 (Figure 48).

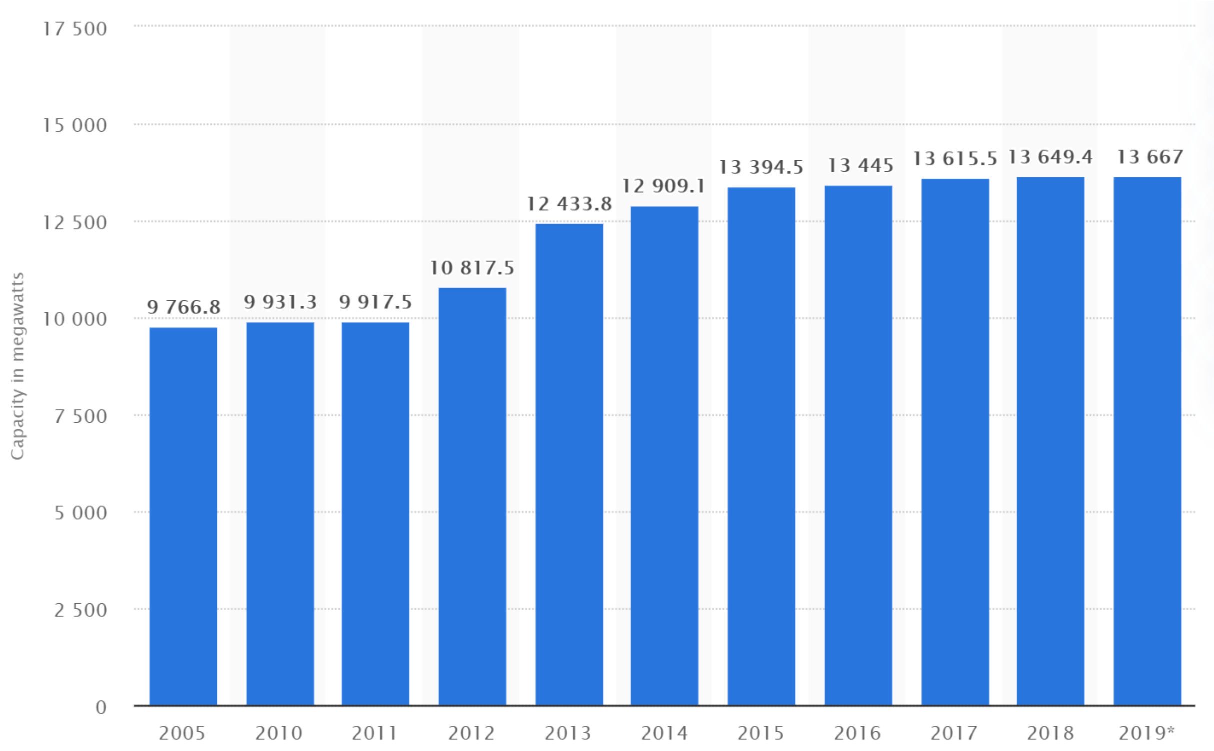


Figure 48: Growth in Singapore's installed electrical generating capacity (2005 - 2019) (Source: https://www.statista.com/statistics/982956/singapore-electricity-generation-capacity/)

Singapore has one of the most reliable electricity grids in the world, with individual consumers experiencing power outages on average of less than a minute a year (Lim, 2018).

v. Cross-border electricity transmission grids

Malaysia and Singapore already have an existing transmission link (Hashim, 2015).

In the planning stages are the join grid linking Singapore, Malaysia, Thailand and Lao PDR. In 2014 the four economies signed a joint statement aimed at developing an integrated power project. The first step of this project was to study the feasibility of supplying 100MW of power from Lao PDR to Singapore through existing transmission pathways (MoEM (Lao PDR) et al., 2014).

Singapore has also reached an agreement on the development of a 3,711 km high-voltage power line that has been approved to link large scale solar arrays in central Australia with Singapore (Recharge, 2020).

2.21 Thailand

i. Renewable energy targets and trend

Thailand's first recorded renewables electricity generation was in 1987. Despite this, 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 49).

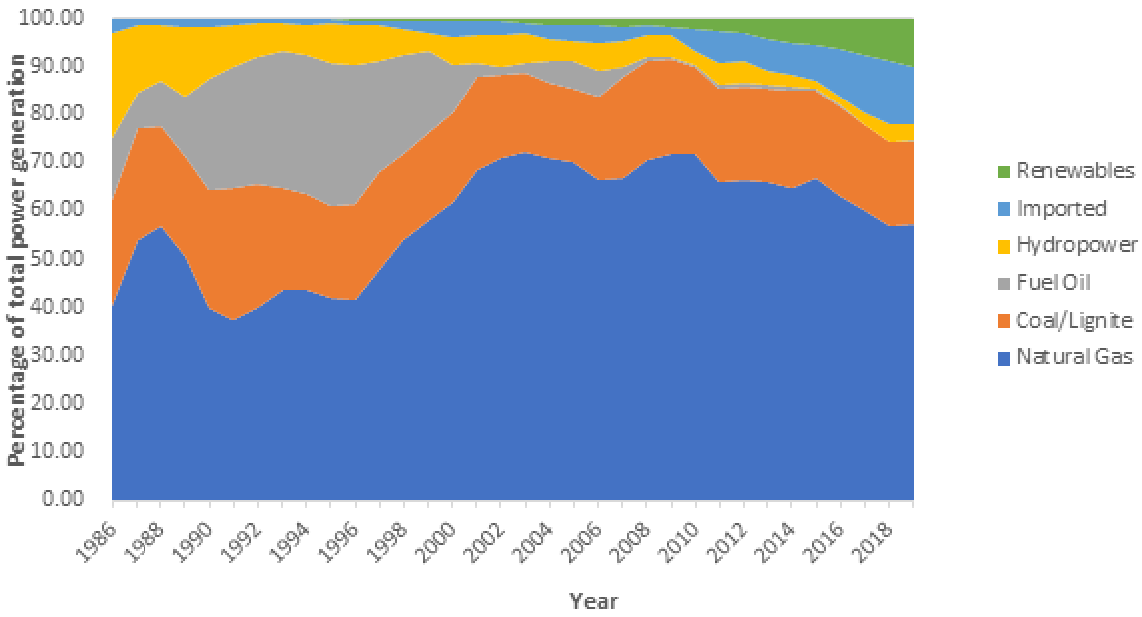


Figure 49: Thailand breakdown of electricity generation by fuel type (1986 - 2019) (Data sourced from: (EPPO, 2020))

Thailand has a target to increase the share of renewables-based power generation to around 20% of total electricity generation by 2036/2037 (Erdiwansyah et al., 2019b; TBoI, 2020). In terms of installed capacity, rather than generation, Thailand's power development plan (2018-2037) (as revised in 2020) specifies that by 2037 there will be 20.77GW of installed renewable generating capacity in the economy (equivalent to 26.9% of total installed capacity) (TBoI, 2020).

ii. Existing, planned and potential energy storage

Despite the growth in renewable energy generation in Thailand in recent years, there has been limited use of EES. The lack of EES may well link to Thailand's focus on distrusted thermal generation that has the flexibility to generate electricity in response to demand (Somcharoenwattana, 2014). The electricity authority, the *Electricity Generating Authority of Thailand*, has established three test sites in Mae Hong Son Province, in Chaiyaphum Province and in Lopburi Province. The Mae Hong Song site has been established alongside a solar PV generation system, and the other two are located at electricity substations in areas with substantial renewable energy generation (ADB, 2020b)

In May 2020 Thailand's first private sector-initiated wind and storage system was announced. This will be a 10MW wind farm linked to a 1.88MWh battery (ADB, 2020c).

iii. Existing, planned and potential pumped storage hydropower

Thailand currently has existing pumped storage hydro capacity of 1GW at the Lam Ta Kong hydropower site (500MW commissioned in 2004, and 500MW commissioned at the end of 2019) (EGAT, 2020). Thailand also has plans for an 800MW PSH system at that Chulabhorn reservoir in North Eastern Thailand that is scheduled for commissioning in 2026 (Kraitud, 2018).

On top of these projects, Blakers et al. (2021) have modelled the PSH storage potential in Thailand to be around 63,000GWh.

iv. Dispatchable power generation capacity and grid reliability issues

In 2018 Thailand's installed power generation capacity was 46GW, and this is projected to grow to 77GW by 2037. The projections for growth in generating capacity include the retirement of 25GW, and the commissioning of 56GW of generating capacity (TBoI, 2020).

Thailand has over 33,000km of transmission lines, ranging from 69kV lines up to 500kV lines, and has 224 electricity substations around the economy (EGAT, 2018) (see also Figure 50).

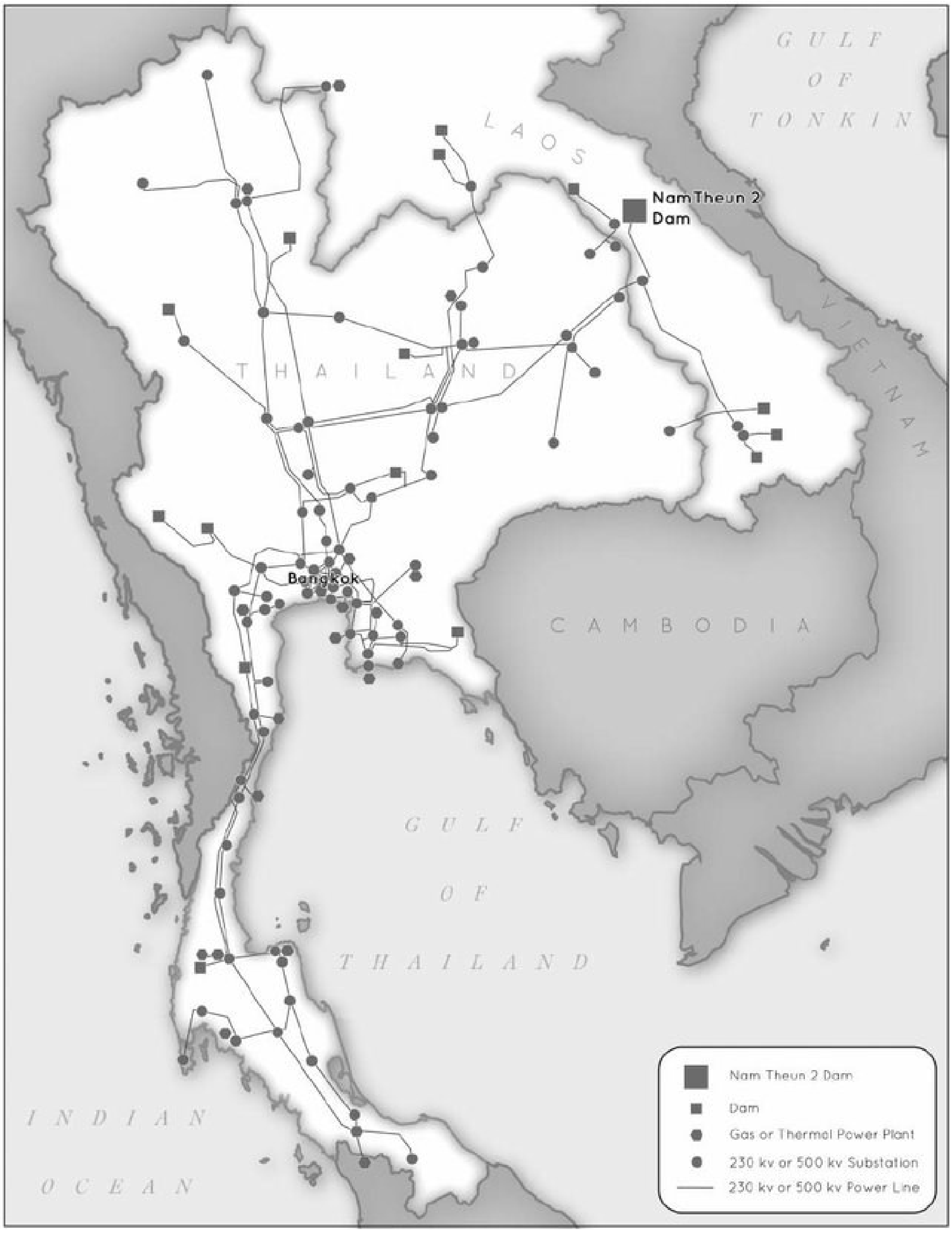


Figure 50: Thailand's electricity transmission network and major generators as at 2015 (Source: (Baird and Quastel, 2015))

Searches of the literature and Thai government websites did not produce any grid reliability data.

v. Cross-border electricity transmission grids

Thailand has cross-border electricity transmission links in five places with Lao PDR, in two places with Cambodia, in one place with Malaysia and in one place with Myanmar (planned completion date of 2016) (ASEAN Secretariat, 2011; Baird and Quastel, 2015).

2.22 The Philippines

i. Renewable energy targets and trend

As of 2016 the Philippines energy sector was reliant on imports for 44.7% of its total energy supply, which was made up almost exclusively of oil and coal imports, along with some biofuels (0.3% of total energy supply was imported biofuels). The breakdown of the 55.3% of domestically generated energy in the Philippines is shown in Figure 51.

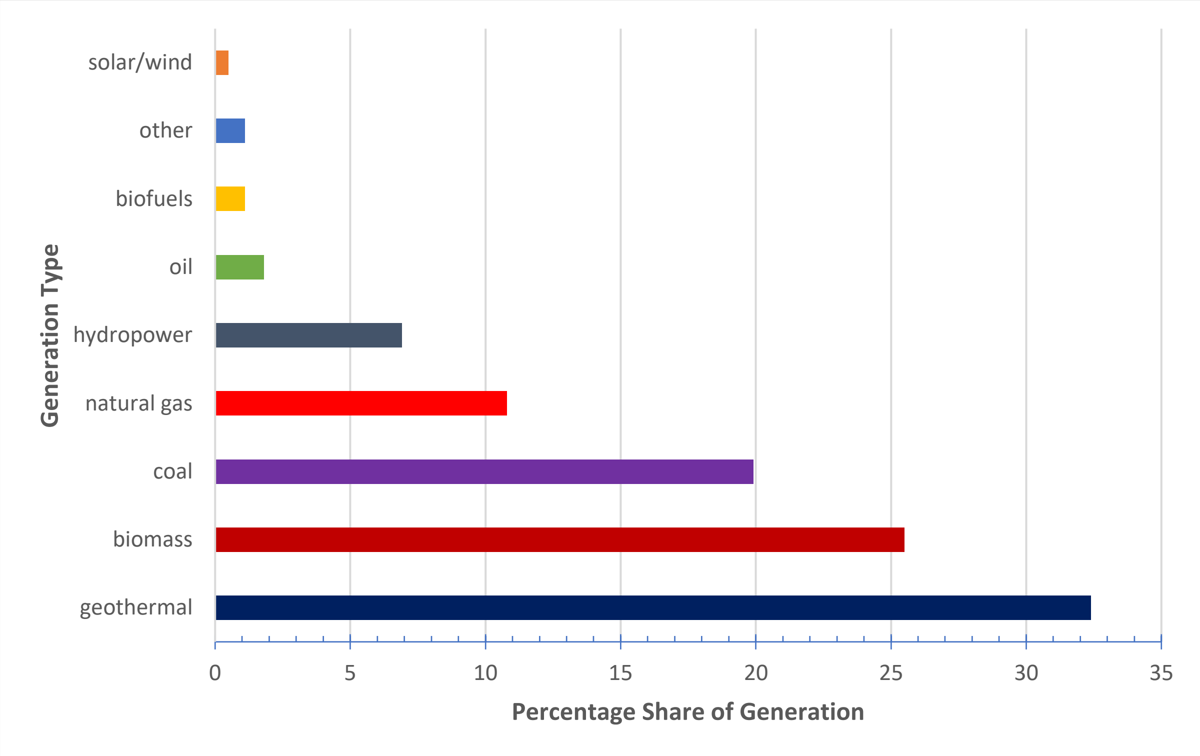


Figure 51: Comparative share of domestically produced energy in The Philippines (Data from (Posadas, 2017))

In 2018 renewable energy generation technologies in the Philippines (hydropower, wind, solar, geothermal and biomass) generated a combined 23,183GWh of electricity (24.6% of total electricity generated), of which 9,605GWh was produced by hydropower facilities (Hydropower & Dams, 2019). The Philippines renewables-based generating capacity includes a 2.8MW waste-to-energy plant, which has been installed in a food processing factory (Roque, 2017). The Philippines has a target of 15GW of installed renewable generating capacity by 2030 (Erdiwansyah et al., 2019b).

The Philippines has developed a Renewable Energy Roadmap, covering the period 2017 – 2040. The basics of this roadmap are shown in Figure 52.

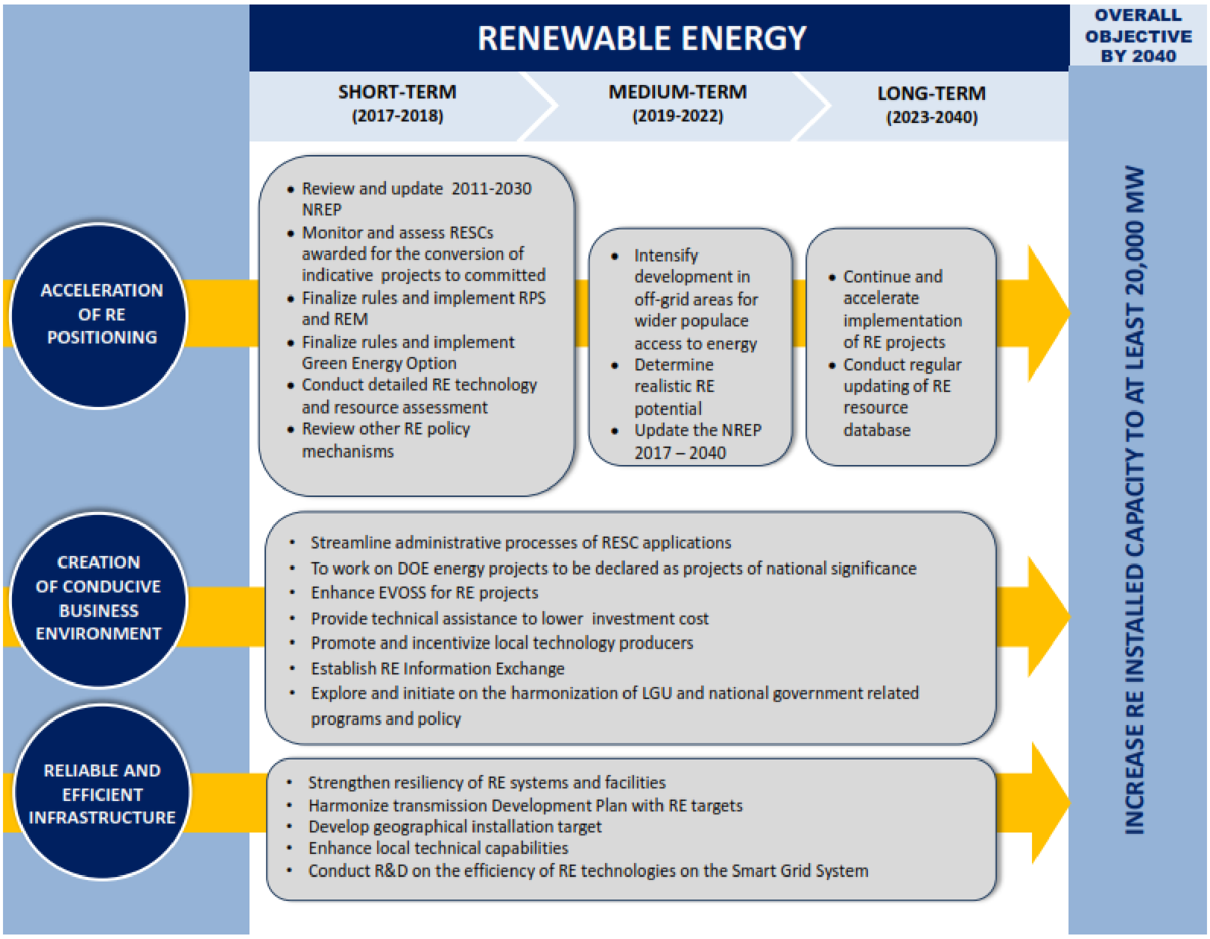


Figure 52: The Philippines Renewable Energy Roadmap (2017 - 2040) (Source: (DoE (Philippines), 2017))

To enable growth in renewables, the Philippines established feed-in tariffs in 2012 (Figure 53).

Source	Feed-in Tariff (per kWh)
Solar	9.68 PHP (24 cent USD)
Wind	8.53 PHP (21 cent USD)
Biomass	6.63 PHP (16 cent USD)
Hydro	5.90 PHP (14 cent USD)

PHP to USD conversion rate used: 1 PHP = USD$0.0245

Figure 53: Feed-in tariffs in the Philippines (2012) (Source: (Energypedia, 2018))

ii. Existing, planned and potential energy storage

In 2019 the Philippines Department of Energy (DoE) released a circular on energy storage, titled "Providing a Framework for Energy Storage System in the Electric Power Industry". This circular notes that energy storage systems (ESS) include four main storage technologies (i) battery systems, (ii) compressed air systems, (iii) flywheel systems, and (iv) PSH systems (DoE (Philippines), 2019).

Battery energy storage is gaining some traction in the Philippines, with 2MW of grid connected storage unveiled in October 2019 50km north of Manila, with other battery storage systems in planning stages (Energy Storage News, 2019).

iii. Existing, planned and potential pumped storage hydropower

Currently under construction PSH projects are the 500MW Wawa project and the 500MW Kibungan Badeo PSH scheme (Harris, 2017; Hydropower & Dams, 2019).

In January 2020 government approvals were granted for the development of a 120MW PSH project in the north of the Philippines, in Nueva Ecija Province (Hydro Review, 2020).

Blakers et al. (2021) have modelled the potential PSH storage in the Philippines, indicating there is around 63,000GWh of potential storage available across more than 5,000 sites.

iv. Dispatchable power generation capacity and grid reliability issues

The Philippines installed electrical generating capacity was 22.3GW in 2017 (Fuentebella, 2018). Of this total, around 1GW of installed capacity are linked to the Luzon, Visayas and Mindanao grids (NGCP, 2020). The Philippines electrical grid operator (NGCP) is investing in smart grid transformers to improve grid reliability and energy distribution (Nhede, 2017).

v. Cross-border electricity transmission grids

There are currently no cross-border electricity transmission grids linking to the Philippines, although there are plans to construct links to the Malaysian state of Sabah (north-eastern Borneo) (ASEAN Secretariat, 2011).

2.23 United States

i. Renewable energy targets and trend

Renewable-based electricity generation in the United States has been a part of the energy mix since the 1950s, and has grown slowly but steadily over time. Including hydropower, renewables-based generation reached 11% of electricity production in 2019, and 8.6% of generation if hydropower is excluded (Figure 54 and Figure 55).

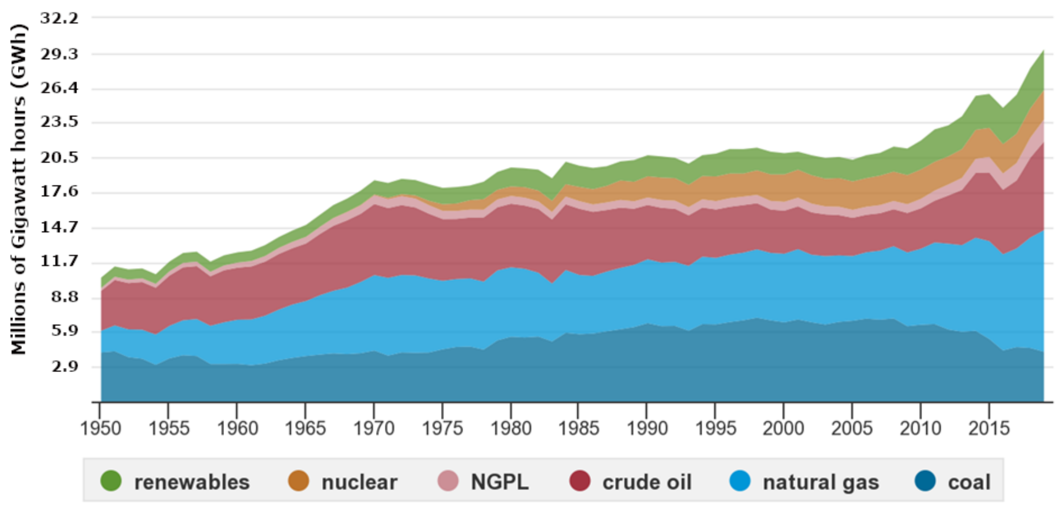


Figure 54: U.S. Primary Energy Production by Source (1950 - 2019) (Source: (U.S. Energy Information Administration, 2020))

Note: conversion was from British Thermal Units (BTU), using the following conversion: kWh =Btu (I.T.) x 0.00029307

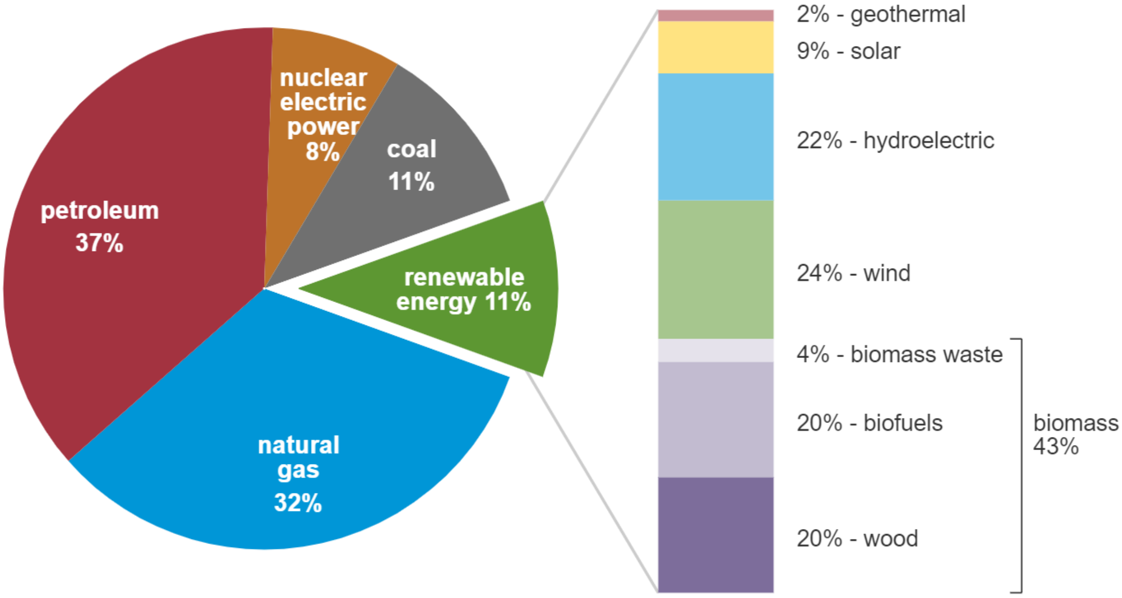


Figure 55: United States electricity production by source in 2019 (Source: (U.S. Energy Information Administration, 2020))

Clean energy goals have been supported by the population in the United States, leading to state governments adopting aggressive policies and standards, such as the state-based renewable portfolio standards (RPS), with 29 states and the District of Columbia (Washington D.C.) having adopted RPSs by 2018. Prior to 2018, the last state to adopt an RPS was Vermont in 2015. However, 5 of these jurisdictions updated their RPS targets in 2018 or early 2019, continuing a state-based trend evident in the Unites States (Figure 56).

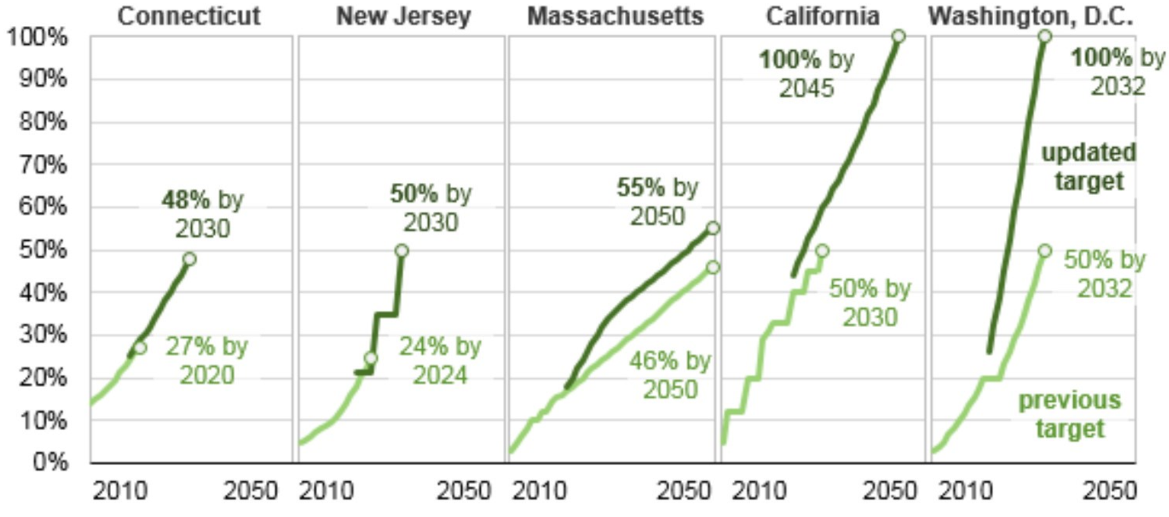


Figure 56: Extended targets announced in 2018/2019 by five United States' jurisdictions (Source: (U.S.EIA, 2019a))

ii. Existing, planned and potential energy storage

At least 97% of energy storage capacity in the United States is PSH, with batteries, thermal storage systems, and other storage technologies combining to a total of less than three percent of grid managing solutions (NHA, 2018).

iii. Existing, planned and potential pumped storage hydropower

Almost all PSH systems in the United States were built in the 1960s, 1970s and 1980s, and PSH forms the United States' largest electricity storage technology (Figure 57).

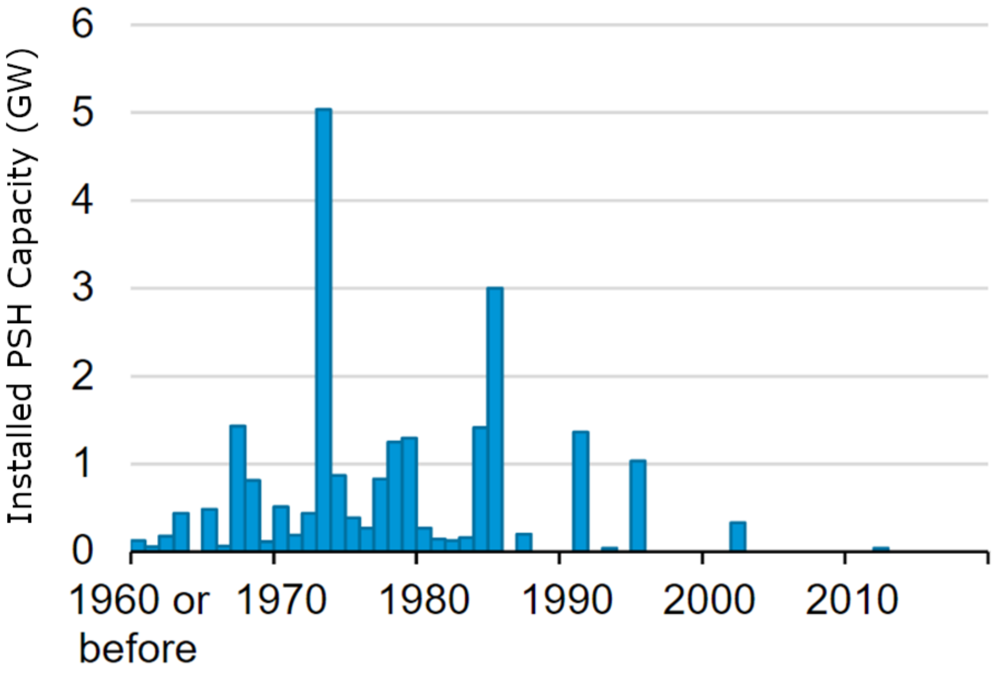


Figure 57: Operating PSH in the United States by commissioning year (Source: (U.S.EIA, 2019b))

The total existing PSH capacity in the United States is 22.9GW (IHA, 2018), and there is an estimated 30GW of untapped PSH potential in the economy, with a total storage capacity of around 1.4 Million GWh (IHA, 2020a; RE100 Group, 2021)

iv. Dispatchable power generation capacity and grid reliability issues

At the end of 2019, the United States' installed electricity generating capacity was 1,100GW (U.S.EIA, 2020).

As the United States' domestic grid has over 30 interconnections with Canada, the two economies have a common *North American Electric Reliability Corporation*, which reported that in 2019 it provided 99.995% reliability (NERC, 2020).

v. Cross-border electricity transmission grids

Nine percent of Canada's electricity production is shared with the United States. All Canadian provinces have one or more transmission lines linking them to states in the United States (NERC, 2020). The United States also has transmission links with Mexico, most of which are less than 100MW. There are also plans to build large scale links between Mexico and California's Imperial Valley (Fairley, 2017).

2.24 Viet Nam

i. Renewable energy targets and trend

Viet Nam's renewable energy generation up until 2015 almost exclusively rested with hydropower (ACE et al., 2018; Gerner et al., 2017). Since then, the county has begun installing solar PV at the utility-scale (both terrestrial and floating systems), as well as introducing feed-in tariffs for rooftop solar and installing wind turbines. The growth in renewables was supported by Viet Nam's 7th Power Development Plan (2011 – 2020), which included the following targets (World Bank, 2019):

- 6.5 percent of installed generating capacity from renewable sources (excluding large-scale hydropower) by 2020
- 10.7 percent of installed generating capacity from renewable sources (excluding large-scale hydropower) by 2030
- 850MW of installed solar PV capacity by 2020
- 4,000MW of installed solar PV capacity by 2025
- 12,000MW of installed solar PV capacity by 2030

The targets outlined in the 7th Power Development Plan have since been updated, with Viet Nam's most recent non-hydro renewables-based power generation capacity targets being 12.5% of total generating capacity by 2025 and 21% by 2030 (Erdiwansyah et al., 2019b).

In 2017, in support of solar PV electricity generation, the Vietnamese government issued Decision 11/2017/QD-TTg. This decision established feed-in tariffs for solar PV (World Bank, 2019). By the expiry date of this decision in mid-2019, 4,500MW of solar PV had been installed. Thus, Viet Nam met its 2025 solar PV target (in MW) over six years early (World Bank, 2019).

In 2020 Viet Nam developed and issued a revised energy development strategic orientation to 2030 with a vision to 2045 under Resolution 55-NQ/TW, which had revised guidelines for the energy sector in general and renewable energy in particular. Under this revised orientation, renewable energy generation is targeted to be around 15–20% of total generation by 2030, and 25–30% of total generation by 2045 (Sanseverino et al., 2020).

Figure 58 shows Viet Nam's power generating capacities in 2014, broken down by primary generator types.

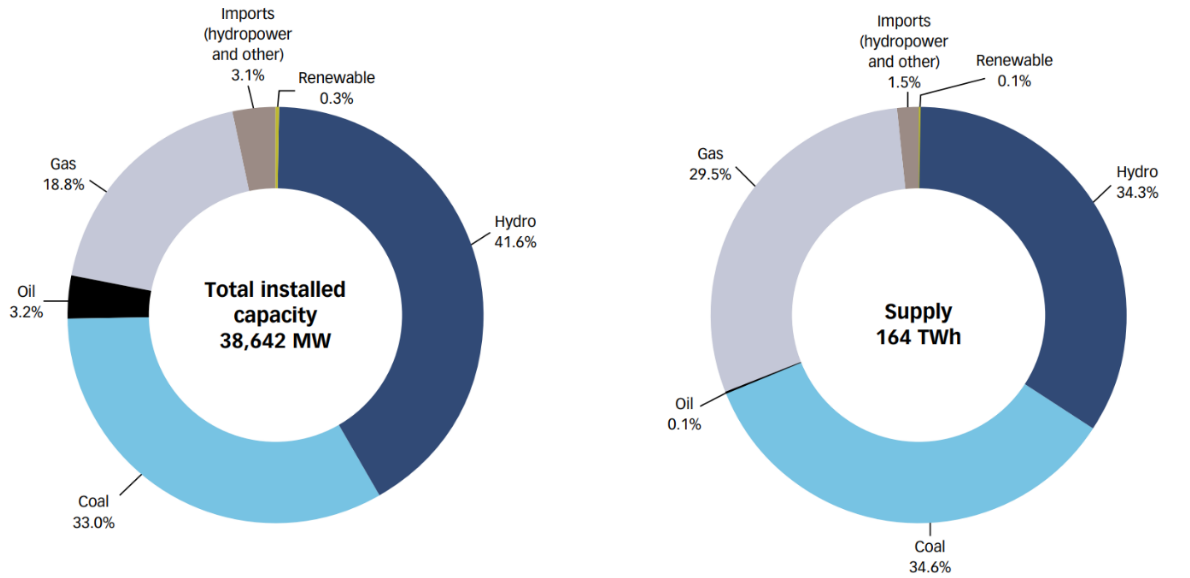


Figure 58: Viet Nam's power generation mix, 2014 (Source: (Gerner et al., 2017))

Projected power supply capacity in Viet Nam is shown in Figure 59, showing that there is significant expected growth in renewable generation capacity, particularly in Solar PV systems and in wind generation systems. There will also be some growth in biomass generation and in small hydropower, although large hydropower is not expected to grow (Gerner et al., 2017).

The Institute for Sustainable Futures, from the University of Technology Sydney, has modelled several scenarios for growth of renewables in Viet Nam, a ***reference*** scenario based on existing power plans in which fossil fuel still accounts for around 80% of electricity generation in 2030, an ***RE1*** scenario, in which fossil fuel accounts for about 55% of electricity generation in 2030, and an ***RE2*** scenario, in which fossil fuel-based electricity generation will account for around 37% of production in 2030 (Teske et al., 2019). In their analysis, they found that up to 2030 the fuel costs in the ***Reference*** scenario would offset the renewable energy generation investments required for the ***RE1*** scenario, so the two scenarios would be cost neutral to 2030. While the ***RE2*** scenario requires significantly more investment in renewable energy systems, the overall fuel cost savings result in this scenario having a cost benefit of USD$6.5 Billion up to 2030 (Teske et al., 2019).

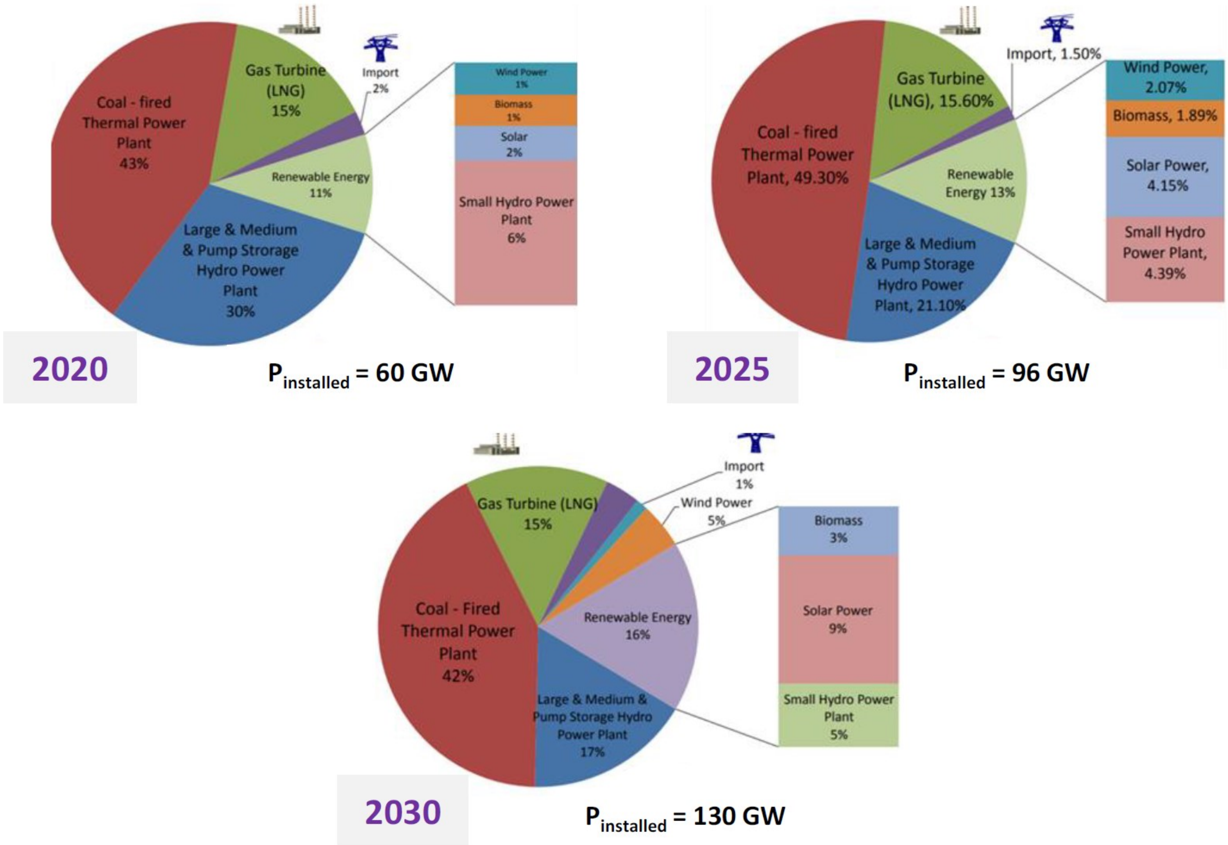


Figure 59: Viet Nam's electrical power generating capacity and sources projected to 2030 (as per Viet Nam's PDP 7 (2011 to 2020, with projections to 2030 (Source: (Vu et al., 2019))

ii. Existing, planned and potential energy storage

It is anticipated that battery storage will become the dominant storage system for balancing Viet Nam's renewable generation of electricity. This is because Viet Nam is only expected to require short duration storage (of up to a few hours) and for this, batteries represent the lowest cost option, particularly as cost per kWh for batteries is expected to continue decreasing. However, even if battery price reductions are not as significant as expected solar PV and batteries are still expected to the primary renewable generation and storage components in Viet Nam, although wind and PSH would have a larger role in this situation (EREA and DEA, 2019).

Viet Nam has recently signed an agreement for an electrical energy storage feasibility study with General Electric (Jabour, 2019).

iii. Existing, planned and potential pumped storage hydropower

PSH has been discussed in Viet Nam since the early 2000s (Gerner et al., 2017), and Viet Nam's first PSH system will be located at the Bac Ai reservoir. It will use four reversible pump-turbines that have a combined power generation capacity of 1,200MW. Viet Nam Electricity (EVN) anticipates that the Bac Ai PSH system will be completed in 2028 (EVN, 2020). There are also another four PSH facilities in various stages of planning and feasibility studies, with Viet Nam's Power Development Plan (7.3) showing a total installed generating capacity of 2,400MW by 2030 (Gerner et al., 2017). Linked to this, EVN has a partnership with General Electric, and the two organisations have announced plans to work cooperatively to implement further PSH systems in Viet Nam (EVN, 2019).

Despite the planning for PSH development in Viet Nam, the potential for PSH to contribute to Viet Nam's electricity network appears limited (EREA and DEA, 2019; Gerner et al., 2017), with a total economically viable capacity of only around 1.5GW (Gerner et al., 2017)

iv. Dispatchable power generation capacity and grid reliability issues

In 2017, Viet Nam's electricity generating capacity was 42GW, over a third of which came from hydropower and about a third from coal-fired thermal power stations (ITA, 2019). While data on the dispatchability of this power was not available at the time or writing, modelling has been done that shows with a strong transmission system Viet Nam's grid should be able to support up to two thirds of overall generation before EES is required at scale (Kies et al., 2018).

v. Cross-border electricity transmission grids

The governments of Viet Nam and Lao PDR signed an MoU in 2017 for increasing imports of hydropower-produced electricity from Lao PDR to southern Viet Nam up to 1GW by 2020. This MoU is being backed by improving transmission networks, which will be necessary for cross-border imports (Gerner et al., 2017).

3. CONCLUSIONS

The APEC economies have a wide range of histories and experiences with electrical storage and PSH. Ranging from economies like Japan, China and the United States, who have been investing in PSH for many years to economies like Brunei that have been using their existing natural resource wealth, but are now beginning to explore both electrical energy storage and renewable power generation possibilities.

With the rapid growth in adoption of variable renewable generators like wind and solar across the APEC economies, electrical energy storage systems are becoming more and more important. For eleven of the 24 economies considered in this background paper there was no evidence found of existing energy storage systems, and for nine of the economies there is no available evidence for plans for energy storage systems.

Of the 24 economies considered here, all except three have significant potential for installing PSH systems. The economies without PSH potential are Brunei Darussalam, Hong Kong and Singapore. However, for each of these economies there is potential in neighbouring economies to which there are existing or planned electricity transmission links.

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Please note that some details in the reference list have been amended to fit with accepted APEC nomenclature. Square brackets have been placed around any affected text.

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Annex 1

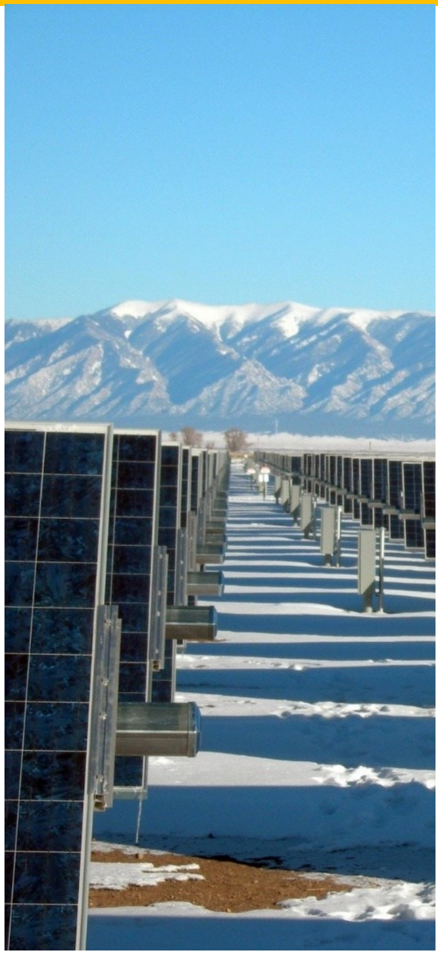
Policy Brief

APEC Workshop on the use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply

Context

Growth in renewable electricity generation is driven by two primary factors:

1. *Declining costs of producing electricity from renewable sources*
2. *Global and domestic policies seeking to incentivize clean electricity sources, due to concerns over local particulate and other emissions as well as greenhouse gas emissions*



Source: https://www.pexels.com

The main renewable-based electricity generation is from wind and solar. Both of these require electrical storage because electricity production often does not coincide with demand. For example, solar peak production is in the middle of the day, but residential energy usage peaks are in the evening.

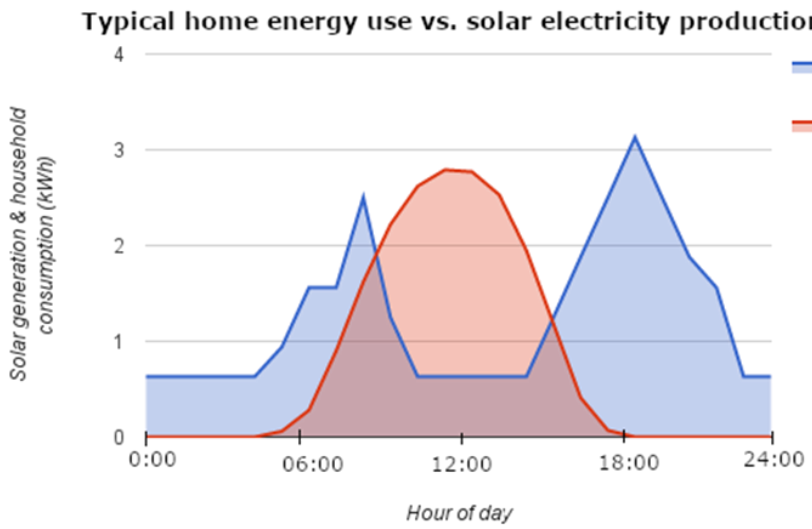


Figure 1: Typical home energy use vs. solar electricity production
(Source: https://www.solarchoice.net.au/blog/solar-self-consumption-overview)

Storing electricity

A residential, or other solar generator, may choose to sell excess electricity (e.g. produced in the middle of the day) to a power utility, or they may decide to install batteries. For grid-scale applications the same principles apply, however there are several electrical energy storage (EES) technologies that have different characteristics, costs, and are suitable for different purposes.

Table 1: Characteristics of different electrical energy storage technologies (Source: (Berre, 2016))

Technology	Capital costs (USD/kWh)	Operation and maintenance costs (USD/kW/yr)	Useful life (years)	Useful life (cycles)	Characteristics
Pumped Storage Hydropower	600 – 2,000	3	50+	N/A	Grid-scale power
Flywheel	250 – 300	0.004	15	20,000	High power short duration bursts
Chemical batteries	1,000 – 4,000	0 - 80, depending on technology	5 – 15	1,000 – 2,500	Fast switching, can be scaled-up
Compressed air	400 - 800	19	20 – 40	N/A	Works in conjunction with gas turbine
Flow batteries	600 – 1,500	70	5 – 10	12,000	Easy to scale-up in size, wide operating temperature

Policy Brief: Pumped Storage Hydropower for APEC Economies

Pumped Storage Hydropower (PSH) works by pumping water from a lower reservoir to an upper reservoir when there is an excess supply of electricity, and releasing the water from the upper reservoir through a hydropower turbine when there is demand for electricity (Figure on right).
As a grid-scale electrical energy storage technology, PSH:

- *Is a mature technologically proven EES.*
- *Is the most efficient technology available for grid-scale storage of electricity*
- *Can be complemented in the grid with other EES options that can provide faster switching speeds and better frequency control;*
- *Must be located in a suitable geographic area;*
- *Can be co-located with renewable energy generation technologies such as photo-voltaics (PV), floating PV and wind.*

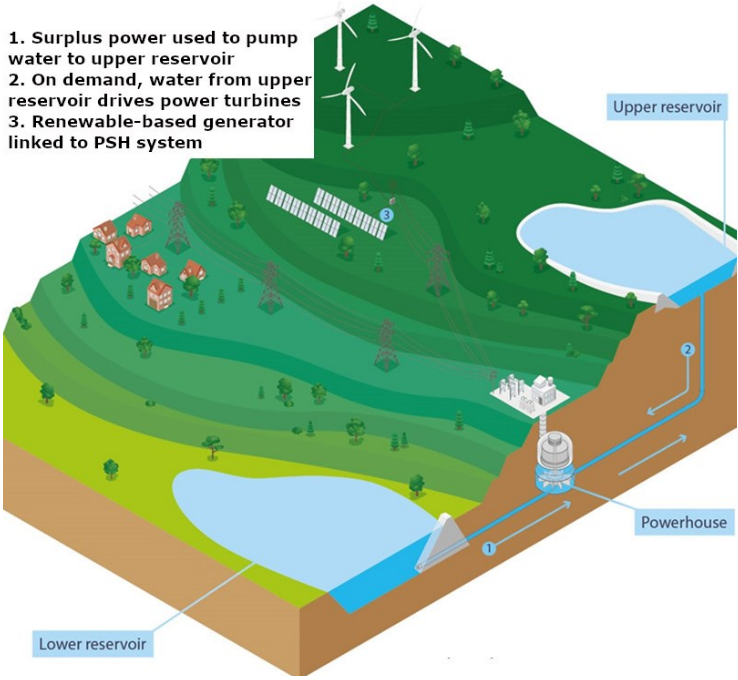


Figure 2: Schematic of a typical PSH configuration (Source: (IHA, 2019))

Regulatory and market setting to facilitate energy storage

PSH requires a large upfront capital cost. Appropriate regulatory and market settings are needed to under pin investment in energy storage. Governments who wish to support development of energy storage systems need to ensure that their markets value ancillary services, including: current and voltage stability (system strength), available generating capacity on the grid in case a generator goes offline (operating reserve), adjustable turbine speed (frequency control) and ability to instantaneously respond to load changes (synchronous inertia).

The technologies used in PSH developments means that the proportion of imported materials may be modest compared to the bulk of expenditure (typically 75%) on indigenous engineering and construction, which generate a lot of local economic benefits.

Resources for locating, costing, and understanding sustainability around PSH systems

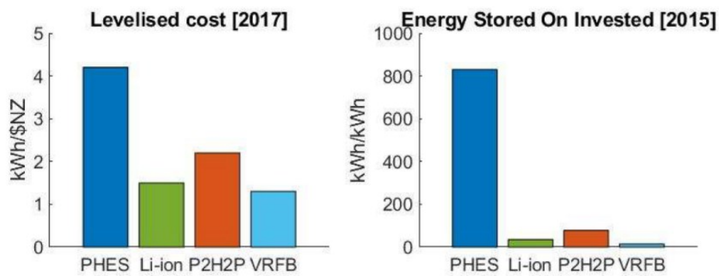
Deciding where to build your PSH system

There are a number of resources that can help with locating and designing a PSH system for your economy. The Global Pumped Storage Hydropower Atlas Project has mapped 616,000 potential PSH sites with a combined storage potential of 23 million Giga-Watt hours of electricity. The atlas, including detailed zoomable maps, is available here: http://re100.eng.anu.edu.au/global/

The economic, environmental and social costs of building PSH systems can be reduced by re-operating existing reservoirs, and by siting developments near existing roads and power transmission lines. The benefits can be maximized by locating PSH in solar and wind renewable energy development zones or near demand centers.

PSH system costs and performance compared with other EES technologies

For grid-scale applications, PSH is the most cost efficient EES available. For example, Figure 3 compares PSH with Lithium-ion batteries, Hydrogen storage and Flow batteries.



PHES: Pumped Hydro-electric Storage (in this paper, this technology is referred to as Pumped Storage Hydropower (PSH);
Li-ion: Lithium-ion batteries;
P2H2P: Power to Hydrogen to Power;
VRFB: Vanadium Flow Redox Batteries

Energy Stored on Invested: the ratio of lifetime electrical energy returned by a device compared with the energy to build the device

Figure 3: Comparison of different energy storage options (Source: (McQueen, 2019))

More detail on EES costs and performance assessments have been reported in detail in the 2020 Grid Energy Storage Technology Cost and Performance Assessment, available here: https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf

Kidston Solar Farm and PSH System, North Queensland (Source: Genex Power)

Assessing the sustainability of your PSH system

Use of renewable generating technologies is growing in order to combat the environmental and social costs associated with fossil-fuel based electricity generation. A number of tools have been developed to help assess and manage social and environmental impacts associated with PSH.

Sustainability tools for assessing and managing both social and environmental impacts of hydropower (including PSH) are available at: https://www.hydrosustainability.org/hydropower-sustainability-tools

Minimizing environmental and social impacts

There are a number of ways in which PSH systems can be located and designed to minimize impacts on the environment and people based on the circulation of water between two reservoirs and with only minor loss of water:

- ***PSH can be constructed off river on marginal lands and so minimize displacement of people, the inundation of farm land and natural habitats;***
- ***In many cases, brownfield sites such as old quarries or mines can be redeveloped for PSH reservoirs, enabling reuse and rehabilitation of degraded lands;***
- ***In many cases, existing reservoirs can be re-engineered for PSH;***
- ***Including environmental and social considerations early in the planning process can inform the siting and design of PSH, helping to reduce negative impacts***

Re-operating existing reservoirs can enable measures that reduce their social and environmental impacts, for example, using the lower reservoir for regulation for environmental flow releases.

Expanding the use of PSH to support growth in renewables-based generation of electricity

There are four key opportunities for expanding the use of PSH for enhancing grid stability and supporting the growth in proportions of renewable-based electricity generation in APEC economies:

- ***An expert team to work with select economies to map out and scope PSH potential on-the-ground;***
- ***Assessing the potential of using PSH in projects to inter-connect domestic and regional electricity grids (e.g. ASEAN and the Greater Mekong Subregion);***
- ***Preparing a summary of information availability and gaps on renewable energy potential and electricity market operations (to inform energy storage investments); and***
- ***Preparing a summary of electricity market settings that encourage investments in energy storage, drawing on best practice in APEC economies.***

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Annex 2

Workshop Report

APEC Workshop on the use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply

WORKSHOP REPORT:

APEC WORKSHOP ON THE USE OF PUMPED STORAGE HYDROPOWER TO ENABLE GREATER RENEWABLE ENERGY USE AND RELIABLE ELECTRICITY SUPPLY

Date of workshop: 02 – 05 February 2021	**Prepared for:** APEC and Australian Water Partnership (AWP)
Project Number: EWG 09 2019A	**Prepared by:** Dr Daniel Gilfillan and Prof. Jamie Pittock
Project Title: *APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply*	

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WORKSHOP SUMMARY

Transitioning to greater reliance on renewable energy requires the capacity to store energy so as to ensure that supply from variable solar and wind generators is available to meet demand. Pumped storage hydropower is the technology that has long been deployed and has the greatest current capacity globally to store renewable energy to meet demand.

The APEC/AWP Workshop on the Use of Pumped Storage Hydropower (PSH) to Enable Greater Renewable Energy Use and Reliable Electricity Supply sought to:

(i) Discuss the potential for use of PSH in APEC and three more Mekong economies,

(ii) Help workshop participants to begin identifying opportunities for developing PSH or modifying existing facilities for PSH,

(iii) Discuss social and environmental sustainability protocols for PSH development, and

(iv) Examine possibilities for further PSH development in the Asia Pacific region. The workshop drew on a background paper describing the status of PSH in the 21 APEC and 3 extra Mekong economies.

This workshop was designed to build on APEC's longstanding commitment to increase the use of renewable energy among its member economies. For example, in 2014 APEC announced that members were incorporating measures to double the renewable energy share of electricity generation among member economies by 2030. The announcement also referenced other APEC projects focussing on renewables growth, including a low carbon towns initiative based on feasibility testing in the real world (APEC Energy Working Group, 2014*). Since then, the APEC Secretariat has published numerous papers focussing on renewables technologies, their integration into mainstream electricity grids, as well as the links between renewable energy and sustainable cities (APEC, 2020*).

It was noted by workshop participants that the background paper describing the status of PSH in the 21 APEC plus 3 additional Mekong economies should be the basis for a short (10 – 15 minute) presentation to the senior officials at the APEC Energy Working Group. This presentation should focus on the three takeaways in terms of understanding PSH and key actions that should be taken. The three takeaways from the background paper are described in the table below:

No.	Key Understandings	Key Actions
1	Growing renewable based generation of electricity will require deployment of large quantities of Electrical Energy Storage (EES)	Ensure that energy forecasting plans take into account growth in renewable-based generation of electricity (and the need for EES)
2	PSH is the most mature, widely deployed and technically proven EES system globally	Integrate PSH into domestic energy planning
3	There are a variety of high-quality tools and resources available for siting, designing, ensuring sustainability of, and operating PSH	Make use of the available tools to simplify PSH development and operation

** Full bibliographic details are provided in the reference list to the technical report that forms an integral part of this workshop, informing the workshop and revised in response to comments from workshop participants*

1 INTRODUCTION

1.1 Project overview

With growing use of variable renewable energy generation such as wind and solar photovoltaics (PV), the use of electrical energy storage (EES) systems is being increasingly recognised as an essential grid component that adds to grid stability and performance. Prior to the workshop, the conveners prepared a background paper on PSH across the 21 APEC economies. The background paper provided an introduction to PSH, as well as covering the following topics for each economy:

(i) renewable energy targets and trends;

(ii) existing, planned and potential energy storage; and more specifically,

(iii) existing, planned and potential pumped storage hydropower;

(iv) dispatchable power generation capacity and grid reliability issues; and

(v) cross-border electricity transmission grids.

1.1.1 Administration

The workshop was run by the Australian National University (ANU) in collaboration with the International Centre for Environmental Management (ICEM).

The workshop was very successful, with 85 speakers and other participants logging in over the four days. There was particularly strong engagement with a view to implementation by energy agency staff from Chinese Taipei, Chile, Cambodia, Malaysia, Myanmar, Thailand, Viet Nam. There was strong non-governmental organisation (NGO) engagement from Cambodia, Indonesia and the World Wide Fund for Nature (WWF). The participants from the United States Department of Energy were very helpful expert contributors.

The gender breakdown of participants is included in the table below. The workshop organisers were able to confirm gender for 73 of the 85 participants. Of the 73 for whom gender was confirmed, ~22% (16) were female, and ~78% (57) were male. For follow-up activities the IFC's "Powered by Women Initiative"[1] will be considered as a source or ideas for ways to increase the role of women.

Gender	Number of Participants
Male	57
Female	16
Not reported	12
Total	**85**

1.1.2 Participant Feedback

1 https://www.ifc.org/wps/wcm/connect/industry_ext_content/ifc_external_corporate_site/hydro+advisory/resources/powered+by+women

Workshop participants were given the opportunity to respond to surveys throughout the workshop, with a survey administered on the final day asking more in-depth questions about the workshop, how participant understandings of PSH had grown and requesting recommendations for improvements.

1.1.2.1 Surveys during the workshop

Participants rated the workshop very positively. Of participants who completed a survey during the workshop, the average rating was 9 out of 10. Survey respondents liked different aspects of the project, but particularly noteworthy were the number of responses valuing the opportunity for everyone to participate and comment and to interact with people from different economies and regions. In terms of comments for improvements, there was a suggestion that several slides should be shown at the beginning of each session to remind participants about the contents of the pre-recorded presentations, and that a summary of session key discussion points should be shared (implemented on days 3-4). The full survey results for the surveys administered over the course of the workshop are included in Appendix 4.

1.1.2.2 Final survey

A further survey was administered on the final day to get more in-depth feedback from participants. The average rating for the workshop given by respondents was 9 out of 10. From these survey responses we note that participants saw a lot of value in getting the presentations ahead of time, and for being able to view them at a time suitable to the individual. Respondents also appreciated the questions from participants, the value in having presenters from a variety of backgrounds and sub-sectors, and the facilitation of the workshop discussions, with effective synthesis of discussion points..

In terms of feedback for future improvement, one respondent noted difficulties with using the GoToMeeting Platform, two respondents requested that in future a summarized version of the relevant presentation should be delivered at the beginning of each session, and one respondent suggested developing a module on educating the broader public about PSH.

In terms of knowledge gained, respondents noted a number of points including: (i) knowledge about the case-study examples presented; (ii) understandings about the social and environmental considerations and financing of PSH (including the role of the International Finance Corporation and World Bank can play in accelerating uptake of PSH); as well as (iii) knowledge about the tools available for assessing feasibility of potential PSH systems.

There was also an indication from respondents that they valued the opportunity to gain direct knowledge from the expert presenters and intend to further interact with them. This highlights the value in bringing APEC economy energy experts together with the expert presenters on PSH.

1.1.3 Synergies with other APEC activities

There are linkages and synergies between this project and two other APEC projects of note:

1. The APEC Energy Working Group (EWG) and its expert groups and task forces are working on projects with ambitious goals and targets that require extensive data collection and analysis. Each APEC economy has excellent universities that could help fill this data collection and analysis need by enabling faculty to teach project-based courses with students doing research to support the work of the EWG and its subfora. Our online workshop in June 2021 will bring together APEC members, faculty from APEC universities, and members of APERC to talk about potential EWG/university collaboration.

   The workshop will identify how to distinguish the most appropriate projects, best practices for communication, potential collaborations between different APEC universities, and methods for sharing results from course research projects. The workshop will provide an excellent networking opportunity to begin the development of a consortium of universities in APEC economies to work in collaboration with the EWG and APERC on EWG goals.

If you are interested in the workshop, please contact the project overseer, Dr Katie Purvis-Roberts (kpurvis@kecksci.claremont.edu) for additional information

2. An upcoming APEC energy storage workshop to be held either later in 2021 (as a virtual workshop), or early in 2022 (as a face-to-face workshop). The workshop will focus on a survey of all energy storage elements:
    a. Chemistries,
    b. Devices,
    c. Systems,
    d. Deployment,
    e. The business cases for energy storage,
    f. Safety,
    g. Finance, and
    h. Regulatory issues.

The workshop is expected to have strong participation of experts from both sides of the Pacific.

For more information on this workshop, please contact the project overseer, Dr Imre Gyuk (imre.gyuk@hq.doe.gov).

1.2 Workshop purpose

Energy storage is of growing interest around the world because of the rapid growth in variable renewable energy generation, and the overall purpose of the workshop is to assess development options for PSH as a proven energy storage option. Within this overall objective, this APEC workshop was convened to:

(i) Discuss the role of PSH in future electricity systems in APEC and other Mekong economies.

(ii) Help participants to identify opportunities in their economies for modifying existing infrastructure for pumped storage (e.g. disused mines and existing 'run of river' hydropower facilities).

(iii) Develop participant awareness of sustainability protocols aimed at ensuring PSH systems are developed with minimal negative impacts on people and the environment.

(iv) Provide opportunities for networking and for examining how existing programs can be leveraged to enhance the development of PSH development.

These project objectives were achieved through a series of presentations that were made available online prior to the workshop (to allow for participants to view the presentations at a convenient time in their location), with the presenters available in plenary sessions and in one-on-one sessions during the workshop to respond to participants queries.

The workshop was run from Tuesday 2nd February 2021 through Friday 5th February 2021. While the workshop had initially been planned to be run face-to-face, due to travel restrictions relating to COVID-19, the workshop was run virtually. To accommodate this change, each presenter pre-recorded their presentation and the presentations were made available to participants on Friday 29th January through a private YouTube channel (the channel can be accessed through this link: https://www.youtube.com/playlist?list=PLcaocc8ImDhOwRbMRcLstEHiq_qMyGLCH). This allowed participants across time-zones to access and view the presentations at a time of their choosing prior to the workshop plenary sessions.

The workshop itself consisted of two plenary sessions each day where presenters were available to answer questions and take part in discussions with workshop participants. In addition to the plenary sessions there was optional time for participants to book one-on-one sessions with presenters to discuss issues of particular relevance to their economy or circumstances.

The workshop agenda is provided below with times Australian Eastern Summer Time (AEST).

Agenda for APEC Workshop on PSH for Greater Renewable Energy Use and Reliable Electricity Supply (Times in Australian Eastern Summer Time)

Time (AEST)	Tuesday 2nd February 2020	Wednesday 3rd February 2020	Thursday 4th February 2020	Friday 5th February 2020
Day & topic	**1. Introduction to PSH and status in the region**	**2. Opportunities to site PSH systems**	**3. Environmental and social standards for PSH**	**4. Financing PSH and concluding discussions**
9:00 to 10:00 Optional discussions* (to suit the Americas)		Optional bilateral / small group discussions with Dr. Gilfillan &/or Prof. Pittock.	Optional bilateral / small group workshop and discussions with Prof. A. Blakers & Assoc. Prof. M. Stocks.	Optional bilateral / small group discussions with case study presenters, Dr H. Locher, Ms. K. Lazarus, J. Alam, V. Viswanathan and A. Somani.
12:30 Plenary session	a) Introduction to pumped storage hydropower. Prof. Pittock. b) International Forum on Pumped Storage Hydropower – Mr. S. Laws	2. Opportunities to site PSH systems. Exploration of ANU global siting options model. Prof. A. Blakers & Assoc. Prof. M. Stocks.	4. Incorporating PSH in transmission grids. Dr. J. Alam, Dr. V. Viswanathan and Dr. A. Somani.	6. a) Financing PSH projects. Mr. Nicola Saporiti b) PSH for transition to reliable, renewable energy supply, Mr. M. Kennedy
13:30	Break	Break	Break	Break
14:00 Plenary session	1. Role of PSH in future electricity systems. Discussion of draft status report on APEC + other Mekong economies. Dr. D. Gilfillan & Prof. J. Pittock.	3. a) Reusing brownfields sites – 1st case study: Kidston project, Genex Power, Australia. Mr. S. Kidston. b) EGAT presents Thai LTK project as 2nd case study	5. Environmental and social standards for PSH. Exploration of tools. Dr H. Locher and Ms. K. Lazarus.	7. Concluding discussions: a) key opportunities, b) actions to assist economies, c) next steps.
15:00	Break	Break	Break	Break
15:30 to 16:30 Optional discussions*	Optional bilateral / small group discussions with Dr. Gilfillan &/or Prof. Pittock.	Optional bilateral / small group workshop and discussions with Prof. A. Blakers & Assoc. Prof. M. Stocks.	Optional bilateral / small group discussions with case study presenters, Dr H. Locher and Ms. K. Lazarus	Optional bilateral discussions Re: PSH role in transition and financing projects. Mr Saporiti & Mr M. Kennedy.
18:00-19:30 Optional discussions* (to suit Asia and Oceania)			Optional bilateral / small group discussions with case study presenter Dr. S. Sparkes.	

- Core sessions with expert speakers are highlighted in green.
- Workshop participants can choose to book 20-30 minute bilateral or small group discussions with expert presenters to explore the circumstances and opportunities for their economies (highlighted in purple). For example, this could be a short workshop on the use of key tools such as the sites atlas or sustainability assessment. These sessions are repeated so that different time zones can attend.

2 WORKSHOP PROCEEDINGS

The Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply was attended by 85 participants from 12 APEC economies plus 4 non-APEC economies. The economies represented at the workshop were: Australia, Chile, Chinese Taipei, Hong Kong, China, Indonesia, Italy, Japan, Malaysia, People's Republic of China, Thailand, United States, Viet Nam, Cambodia, Lao PDR, Myanmar and United Kingdom.

The workshop agenda is included on the previous page. Each presentation was made available to participants prior to the workshop so that they could view presentations at a time of their choosing. The workshop itself was set up as a series of plenary sessions as described below:

2.1 Plenary discussion 1, 12:30-13:30 AEST, Tuesday 2nd February 2021

Introduction and International Forum on PSH

The presentations delivered by Professor Jamie Pittock from the Australian National University (Introduction) Mr S. Laws from the International Hydropower Association (International Forum on PSH) are included in Appendix 3.

The introduction to the workshop highlighted the following:

- Growth of variable renewable energy generators such as wind and solar require storage
- PSH is well proven technically and financially
- PSH has high round trip efficiencies (70 – 80%)
- Provided an outline of topics to be covered in the workshop:
    - Benefits, costs, risks
    - Siting PSH
    - Tools to minimize social and environmental costs
    - Examples of PSH in APEC economies
    - Status of EES and renewables targets in APEC economies
    - Integration of PSH with power grids
    - Project financing

The presentation on the International Forum on PSH covered the following points:

- Challenges in developing PSH (e.g. lack of understanding, financing, lack of incentives)
- Members of the International Forum on PSH
- Forum working groups and activities (e.g. Policy and Market Frameworks, Sustainability, Capabilities Costs and Innovation)

The following points were raised during the plenary discussion:

1. The International Forum on PSH was set up to address common policy and market challenges such as environmental sustainability (e.g. for APEC economies one point of interest in terms of sustainability is that PSH will produce far less e-waste and e-based recycling than batteries).

   Membership is free and all workshop participants are encouraged to participate.

2. Advice on issues like financing and sustainability is planned to be finalised by September 2021 and will be supported by workshops and meetings during the year. This report will be used to provide advice to COP26 in Scotland. This is important as a way to help get to net zero emissions without impacting on system performance.

3. The Forum is interested in receiving further case-study examples such as linking of PSH to floating solar, to batteries and to desalinization plants.

4. The policy environment can reduce revenue uncertainty for PSH investors, for example cap and draw systems that guarantee a minimum return for investors. However contextual factors also play a part - e.g. California has been experiencing blackouts because batteries are not suited to long-duration storage - so they are now proposing PSH systems with 6 to 8 hours storage to enhance grid resilience.

   One issue with financing is that current financial return models generally work on a maximum time-scale of 20 years - this is suitable for batteries, but disadvantages PSH which can have an operational life of up to 100 years without need for major reinvestment.

5. The Forum has a global tracking tool for PSH - the tool shows 9,000GWh of operational storage with many of the 300 - 400 PSH stations performing weekly or monthly storage. Longer-duration storage is linked in these cases to open loop water systems, whereas closed-loop systems often have smaller environmental footprints. However, with proper guidelines, open loop systems can reduce their environmental footprints.

6. The successes of China, the US and Japan in the past with PSH are due to different factors, with the People's Republic of China (PRC) the only economy of the three still investing actively in PSH.

   The PRC's power supply is basically from state-owned utilities that respond to government mandates and are not as constrained by the need to make a profit (e.g. post COVID-19 the PRC announced new PSH projects, but partially this was to generate employment).

   In the US the development of PSH related to WWII reconstruction and there has been little new PSH since the 1980s. There are pipeline projects in the US, however environmental approvals and other lack of a robust market framework is slowing these down.

   Japan is similar to the US with no new projects in the last 20 years. However, outside of Japan, JICA is supporting PSH developments (e.g. in India).

7. Hybrid PSH and battery installations are being discussed, and there are examples, such as in Chile, linking hydropower with batteries.

8. In Indonesia and the Philippines the World Bank is supporting feasibility studies.

9. As we design electricity grids for the future we need to incorporate new technologies such as synthetic inertia for power quality management, however we also have to be aware that we are building on an existing centralised grid system. Synthetic inertia is something that will be explored by the international forum on PSH in its report.

10. PSH will support plans to link grids across regions and domestic boundaries by opening a market for bulk energy storage (e.g. Denmark wind generation and Norway storage).

11. PSH and other storage is also growing in importance because now we are already seeing over supply occasions when renewable generation has to be switched off (e.g. in the US and Canada as well as in other APEC economies).

2.2 Plenary discussion 2, 14:00-15:00 AEST, Tuesday 2nd February 2021

Background paper feedback session

The presentation delivered by Dr D. Gilfillan, ICEM, is included in Appendix 3. The key areas covered in the background paper presentation were:

- Drivers for the need for EES
- Different EES technologies and their characteristics
- Overview of PSH
- Status of PSH in the 21 APEC + 3 Mekong Economies

The following points were raised during the plenary discussion:

1. The words from the APEC agreement in relation to the renewable energy goals are: "Aggregate 50% renewables by 2030".
2. Many APEC economies have announced ambitious goals for emissions reductions (some very recently): China net zero by 2060, US, Japan, NZ, Republic of Korea, and Canada have all announced net zero by 2050. PSH can support achieving these goals. Note also the incredible changes in ambition in the last ten years with more than half of APEC energy use has targets of net zero by 2050.
   a. Note that targets are not enough by themselves, we have to make sure these ambitions are translated into plans;
   b. Think about drivers - levelized cost is a good general driver, but it is not always the only (or main) driver - e.g. China (as noted by Mr. S. Laws);
   c. The workshop background paper could include more on policy frameworks of the different economies.
3. US section - people have supported clean energy goals leading to state governments adopting aggressive policies, including Hawaii net zero by 2045 (this will be challenging and there are opportunities for PSH to support this).
4. Indonesia's target is phrased as 45GW by 2025 (23% of total primary energy supply), and does not refer to a percentage of installed capacity
5. Indonesia has significant PSH potential, but how can it support net zero by 2050. How can Indonesia use PSH to raise emissions reductions ambitions?
6. The technical paper resulting from this workshop (the main section of this APEC report) should be distributable through the APEC website. Therefore, instructions should be included - e.g. how to survey potential sites, key tools, key messages
7. The technical paper resulting from this APEC workshop (the main section of this APEC report) should include a section on economics and financing (business model for PSH, financial advantage from ancillary services, differential between peak and low pricing, financing terms for long-duration investments).

2.3 Plenary discussion 3, 12:30-13:30 AEST, Wednesday 3rd February 2021

Global PSH Atlas Project Session - selecting sites for PSH

The presentation delivered by Assoc. Prof. M. Stocks, ANU, is included in Appendix 3. The Global PSH atlas covered the following:

- An introduction to the open online Global PSH atlas and how to use it
  - Siting of >600,000 reservoir pairs around the world with 23,000 TWh of storage
  - Zooming in on individual sites
  - 3D visualisations with pop-up windows containing key information for individual sites

The following points were raised during the plenary discussion:

1. Batteries for residential use are normally guaranteed for a limited number of cycles. In the case of the Tesla Hornsdale Battery in South Australia it cycles often, but for stabilising the grid, it is not deep cycling for arbitrage.

2. ANU has built a model for comparing costs of PSH development at different sites, but these need to be ground-truthed in each case (also allowing for differences in costs for labour etc… in each case). A simplified methodology for estimating costs was used.
3. ANU have provided only an estimate of total capital cost. ANU have not included financing options in this, so the cost categories do not relate to levelized cost of energy.
4. Shape files showing exclusion areas in particular economies (e.g. social, environmentally sensitive, prone to natural disasters) that people have and could share could be incorporated into ANU's model, but currently the only site exclusion used is protected areas from the World Protected Areas Database.

At the moment GIS layers cannot be exported due to a glitch in the system, but this is being resolved.

5. The Global PSH Atlas team is currently working on including analysis of existing hydropower sites, with a focus on brown field options.
6. The Atlas does not consider transmission links or other elements external to the PSH system itself, because these are subject to change. Economies can overlay their own data and planning processes on the information from the atlas to incorporate these elements.
7. To determine levelised cost for PSH, you assume financing over a fifty-year lifetime (because beyond that the discounting is zero), whereas for batteries you may discount over ten years.
8. It is expected that PSH systems will face lower objections than traditional hydropower because of smaller impacts and land use areas, because they do not flood river valleys and associated farmland, towns and valley areas with high biodiversity.

2.4 Plenary discussion 4, 14:00 – 15:00 AEST, Wednesday 3rd February 2021

Innovative developments: Kidston PSH project using an abandoned gold mine in North Queensland

The presentation delivered by Mr S. Kidston, Genex, is included in Appendix 3. The key points covered in the Kidston PSH case study were:

- Siting of short and long-term investments (renewable generation and storage) together because of size of investments
- Minimizing environmental footprint by using an abandoned asset (abandoned gold mine)
- Funding structure and ownership of the project

The following points were raised during the plenary discussion:

1. A remote PSH location has both positives and negatives - our project has been socially acceptable because of employment we have generated, and labour costs have also been lower than in more central locations. Main challenge with remoteness is distance from load centres and transmission lines, but Kidston has partnered with state government on transmission infrastructure.
2. Water quality has not been a big issue at Kidston, and water supply is secure because of an existing pipeline that was used to fill the gold pit voids 18 years ago.
3. Genex as the project developer has an energy services and storage agreement with the utility Energy Australia - essentially Genex has developed the system and then leases it to Energy Australia who will operate it.
4. Genex received subsidies for feasibility studies from Australian Renewable Energy Agency and hope to receive capital cost subsidies - while batteries are getting close to being viable without subsidies, PSH is not there yet.

5. Environmental permitting is a risk anywhere and sufficient time needs to be allowed for these processes, including making time for high quality stakeholder engagement. Because of long time frames for planning and investment in PSH it makes sense to develop assets with shorter development and planning durations. In the case of Kidston these were adjacent solar and wind generators.
6. Genex has invested separately in battery development in a different site, but because of contractual arrangements with Energy Australia batteries are not currently being considered for use at Kidston for things like reducing system wear and tear.
7. Genex invested first in solar and then wind as a stepping stone to the PSH system. Wind and solar in north Queensland complement each other with generation at different times of day.
8. Choosing a brownfields site involves whittling down options using criteria like secure access to water, access to transmission links, good geology etc… Kidston is lucky enough to receive almost enough rain each year to offset evaporation losses, but banks require more than this - secure water access is vital.
9. Renewable energy zones have a lot of positives, however the co-location of too much renewables generation and storage can limit economic potential.

2.5 Plenary discussion 5, 12:30-13:30 AEST, Thursday 4th February 2021

Session on Incorporating PSH in transmission grids

The presentations from Dr J. Alam, Dr V. Viswanathan and Dr A. Somani, US Pacific Northwest National Laboratory, are included in Appendix 3. The incorporating PSH in transmission grids presentations covered the following key points:

- PSH cost and performance
  - Detailed comparison of different EES technologies
  - PSH cost breakdown (excluding transmission infrastructure)
    - Reference data from literature and commercial databases
    - Stakeholder interviews
- Energy storage research at the Pacific Northwest National Laboratories (PNNL), with links to PSH
  - Illustrative evaluation of PSH by PNNL
  - Consideration of enhanced flexibility (e.g. through PSH battery hybrids)

The following points were raised during the plenary discussion:

1. Some costs for PSH will vary depending on the economy and region (e.g. labour and construction), however turbines and other electro-mechanical elements will not vary significantly;

   Report: *2020 Grid Energy Storage Technology Cost and Performance Assessment* based on US market is available at: https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf
2. To add PSH elements to an existing conventional hydropower system, new electro-mechanicals will be needed (pumping) at around US $467/kW, and usually relocating the generator to a lower elevation to provide head from the bottom reservoir to charge the pump.
3. Shell North America tried to establish a modular PSH system converting existing open loop sites with use of a floating membrane technology - PNNL did modelling for this, which looked positive, however despite Shell achieving all the regulatory permissions the demonstration has not gone ahead. The cost would have been ~$750/kW excluding dead financing, as per the report "Shell Energy North America's Hydro Battery System".

4. Batteries being used in a complementary way within a PSH system have not been trialled, however they have been done in small (50 - 100MW) conventional hydropower systems to help operators avoid the 'rough' operating ranges of the turbines.

2.6 Plenary discussion 6, 14:00 – 15:00 AEST, Thursday 4th February 2021

Session on environmental and social standards for PSH: Exploration of tools

The presentations delivered by Dr H. Locher, hydropower consultant, Ms. K. Lazarus, International Finance Corporation (IFC), and Dr. Stephen Sparkes, International Power, are included in Appendix 3. The key points from these three presentations were:

- Role of hydropower sustainability tools for PSH
  - Differences between conventional hydropower and PSH
  - Tools to ensure sustainability positives outweigh the negatives
  - Evolution of sustainability tools, including uptake of use of hydropower sustainability tools over time
  - The 12 topics included in the Hydropower Sustainability Environmental Social Governance Gap Analysis (HESG) tool (topics align with World Bank Group standards)
  - PSH configurations that are likely to have lower environmental and social impacts
  - Factors beyond project scale that affect hydropower sustainability
- Integrated management through landscape level approaches
  - Environmental, Social, Governance Standards
  - IFC risk management approaches
    - Establishing appropriate risk management systems
    - Stakeholder engagement
  - Addressing gender-based violence and harassment
  - Watersheds: Balancing conservation and development
  - Environmental and social flashpoints
  - Case studies: Cumulative Impact Assessment and Strategic Environmental Assessment
- Challenges and opportunities for PSH: Environmental and Social Perspectives
  - Opportunities and challenges for PSH
    - Integrating E&S elements into planning at earliest stages
  - Environmental and Social Impacts
    - Biology, water quality, socio-economic, downstream
    - Mitigation opportunities

The following points were raised during the plenary discussion:

1. Hydropower Sustainability Assessment Protocol (HSAP) and HESG Tool are tools that can help companies and governments to achieve IFC performance standards.

2. A lot of the project evaluations undertaken using HSAP and HESG are not publicly published - companies have used these to improve internal practices. One issue is how companies collect and store data - often data hasn't been collected and stored in a way that it can be used to to provide an evidence base for HSAP, which highlighted a need for information storage systems within these companies.

3. IFC is bringing data from landscape and corridor studies into databases - e.g. elements to do with levels of rural electrification, isolation and other vulnerability indicators. However, it is important to be cautious in downscaling data from high levels (e.g. economy-wide, global), as assumptions are not necessarily valid at small scales (e.g. ground-truthing can lead to changes in assumptions).

4. IFC requires investors to comply with performance standards, and works with central banks to encourage adoption of social and environmental risk management practices.
5. In terms of use of tools, it can often be challenging to get developers to adopt these tools if they are at a different standard to government regulations.
6. IFC is moving its work in assessing environmental and social impacts prior to the selection of individual projects as this leads to selected projects being more likely to have lower impacts and be more bankable.
7. In some cases civil society organisations use these tools as a basis for endorsing projects, and in the US this has led to some states linking project eligibility to meeting the low impact hydropower organisation's endorsement criterium.
8. There is sometimes grant funding available for assessments with HESG tool (for example), such as through the Swiss development agency.

2.7 Plenary discussion 7, 12:30-13:30 AEST, Friday 5th February 2021

Session on financing for PSH projects and on PSH for a reliable renewable energy supply

The presentations from Mr N. Saporiti, IFC, and Mr. M. Kennedy, GE Renewable Energy are included in Appendix 3, and discussion drew on GE's 2020 report "Pumped Hydro Storage in Australia." The key topics covered in the two presentations were:

- Financing PSH projects
    - Financial products for PSH development
    - Encouraging private sector investment
    - Key risks in financing decisions
    - Choice of business model (e.g. utility owned, capacity contracts, merchant)
- Transitioning to a renewable, cheaper and more reliable electricity supply
    - Energy transition and grid challenges
    - Hydropower enabling the renewable transition
    - Unique capabilities and characteristics of PSH
    - Cost overview of PSH and project optimization

The following points were raised during the plenary discussion:

1. Australia has a data rich environment (pricing, loads, different contributing technologies over time etc…) which simplifies analysis. Conducting similar analysis in other APEC economies would first require an analysis of data availability. It may be possible as a next step from this project to set up a project to collate the available data sets from interested economies (e.g. Chile, Viet Nam, Thailand, Malaysia, Indonesia) as an initial step to generating a white paper like the Australian version.
2. The regulatory environment and other local circumstances can make it challenging to identify least cost solutions for electricity generation including development of PSH. Individual assessments are necessary.
3. In GE Renewables experience, 75% of the cost of a typical PSH development is spent on local content including significant employment. So for each dollar spent around 75 cents should go into the local area. But how to relate those proportions to generating capacity is more challenging.
4. It is important to realise that batteries and PSH perform different roles in grid-scale electricity markets. PSH provides system strength and inertia, but is location specific. In contrast, batteries can be installed wherever you need them and have fast (sub-second) response times

(variable PSH turbines can achieve sub-second switching, but fixed PSH cannot). At the moment PSH is orders of magnitude more cost effective for bulk storage and has a design life-span of around 5x batteries (50 years cf. 10 years). Batteries can fill important grid manipulation roles. There will need to be a mix of both PSH and batteries for the foreseeable future. Recycling of batteries at the end of their useful life is also challenging

5. Financing of international transmission grids is funded through the IFC and international development banks.
6. Converting conventional hydro to PSH normally requires re-engineering of the powerplant, including its location and level in comparison to the lower reservoir. However, it is possible to use existing reservoirs - Snowy 2.0 in NSW is doing this - and you can also tap into existing roads and transmission infrastructure - so there can be significant cost savings in conversion.
7. Refurbishment and updating of PSH infrastructure is possible and there are historical examples of this. It is also important because efficiencies of turbines and other elements improve over time (e.g. more recent PSH uses reversible turbines instead of separate pumps and turbines). Refurbishment timelines depends on usage - e.g. existing Snowy hydro (conventional) is only used when market price is high, so a long time between refurbishments, but Tasmanian hydro assets are used for baseload, so refurbishment timeline is shorter. Market conditions also play a role in determining the benefits that can be gained from refurbishment.

2.8 Plenary discussion 8, 14:00 – 15:00 AEST, Friday 5th February 2021

This final plenary session of the workshop was used to discuss the key findings from the workshop, recommendations for next steps and to finalise the list of key tools that were discussed and highlighted during the workshop. These points are all described in Section 3 (Conclusions and Next Steps).

2.9 Bilateral discussions

The two hours per day available for plenary discussions in the workshop reduced demand for bilateral discussions with the expert presenters. Even so, participants from Cambodia and Indonesia were able to engage in economy specific, detailed bilateral discussions with expert presenters on the PSH siting, and environmental and social governance implications for their economies.

3 CONCLUSIONS AND NEXT STEPS

3.1 Conclusions

The key messages derived through the workshop, and as agreed by workshop participants are:

1. PSH is by far the world's most mature and deployed energy storage technology.
2. Batteries and PSH have complementary characteristics that enable them to fill different roles in the grid. PSH being more aligned with bulk energy storage and longer-term firming, and batteries more aligned with shorter term grid services.
3. By enabling storage of variable renewable energy from solar and wind generators, PSH enables governments to achieve their goals to reduce GHG emissions and transition to renewable energy.
4. The nature and indigenous technologies used in PSH developments can generate a lot of local economic benefits.
5. Capital intensive development up to 10 years, with time-scales being heavily site and regulatory environment dependent, requires enhanced financing models in order to be economically viable.
6. PSH generally has lower environmental and social impacts compared to conventional hydropower but rigorous assessment is needed.
7. There are information and many tools that can help governments and business develop PSH sustainably (see section below on information sources and tools for supporting PSH development).

Revisions to be made (and now incorporated in) the background paper that formed the foundation for the workshop are:

1. By economy, as advised by representatives during workshop.
2. Add clearer outline and table of PSH opportunities and challenges.
3. Add description of the range of forms that PSH could take - this should include a section outlining unusual or advanced ways of doing PSH (e.g. 2 pits) - having a set of examples of novel solutions like this could help stimulate economies that are interested. Emphasise PSH configurations that will provide benefits with lower adverse impacts and fewer objections - enabling PSH to proceed in a timely manner.
4. Add description of the economic and financing mechanisms that favour PSH, and look at regulatory environments that favour PSH.

The key information sources and tools that were highlighted during the workshop to support PSH development are:

1. International Forum on Pumped Storage Hydropower: https://pumped-storage-forum.hydropower.org/
2. US DOE Global Energy Storage Database, which contains hydro: https://www.sandia.gov/ess-ssl/global-energy-storage-database/
3. US DOE PNNL publications: https://www.pnnl.gov/publications-reports > hydropower
4. 2020 Grid Energy Storage Technology Cost and Performance Assessment: https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf

5. Global pumped hydro atlas http://re100.eng.anu.edu.au/global/ or https://nationalmap.prod.saas.terria.io/#share=s-tPEnZ4T5NRAYIiLS0E3ftvcAzb

6. Hydropower Sustainability Tools https://www.hydrosustainability.org/

7. International Finance Corp. environmental and social governance tools, including "Hydropower EIA Manual" (need link) https://www.ifc.org/wps/wcm/connect/Industry_EXT_Content/IFC_External_Corporate_Site/Hydro+Advisory

   https://www.ifc.org/wps/wcm/connect/Industry_EXT_Content/IFC_External_Corporate_Site/Hydro+Advisory/Resources/Tools+and+Guidelines/ (includes link to EIA manual from Nepal)

8. GE Renewable Energy white paper on PSH in Australia https://on24static.akamaized.net/event/28/21/37/3/rt/1/documents/resourceList1606920319599/pumpedhydrostorageinaustralia1606920317182.pdf

9. Global solar atlas: https://globalsolaratlas.info/map

10. Global wind atlas: https://globalwindatlas.info/

3.2 Next steps

The workshop highlighted four important opportunities to further the use of PSH to deliver reliable grids that include growing proportions of renewable energy generators. These four opportunities are summarised below:

1. Potential mapping and scoping of PSH in selected economies. Suggestion is for a small expert team to work with agency staff in volunteer economies to scope options. Potential volunteers may include Chile, Malaysia and Viet Nam. Outputs: expert advice for volunteer economies and case studies for broader APEC consideration.

2. Assessment of potential PSH in grid interlinking projects. Could look at one or more of the major transboundary grid interlinking plans, e.g. ASEAN and Greater Mekong Subregion. These are often focussed on fossil fuel generators and large hydro. Assessment could consider how the proposed grids could evolve to focus on renewable energy zones drawing on solar, wind and pumped hydro.

3. Economy information needs. Presentation from Martin Kennedy, GE Renewable Energy Australia, highlighted the kinds of renewable energy potential and electricity market information required to inform potential energy storage investments. Project could summarise the types of information required, identify good practices in APEC economies and recommend priorities for filling gaps.

4. Regulatory and market settings needed to support greater energy storage development. Most presentations highlight electricity market regulations and settings required to under-pin investment in energy storage. Project could summarise the types of market setting that encourage energy storage, identify good practices in APEC economies and recommend priorities for filling gaps.

   These options for next steps will be further explored and discussed with the APEC Energy Working Group.

APPENDIX 1: PARTICIPANT LIST

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
1	Abhishek Somani	M	USA	Pacific Northwest National Laboratory		x	x		x
2	Anna				x	x	x	x	
3	Anuthida				x	x			-
4	Steivan DEFILLA	M	China	APEC Sustainable Energy Center	x	x	x	x	x
5	Cary Bloyd	M	USA	Pacific Northwest National Laboratory	x	x	x	x	x
6	Camila Vásquez	F	Chile	Chilean Ministry of Energy		x	x		x
7	Carlos Alberto Rojas Zanol	M	Chile	Chilean Ministry of Energy		x	x	x	x
8	Chalishazar, Vishvas H	M	USA	Pacific Northwest National Laboratory			x		x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
9	Chea Piseth_EDC Cambodia	M	Cambodia	Electricite du Cambodge (EDC) / Deputy Director	x				x
10	DDD		Thailand	Electricity Generating Authority of Thailand	x	x			
11	Dr.Kanchit Ngamsanroaj	M	Thailand	Electricity Generating Authority of Thailand	x	x	x	x	x
12	Elena Rose	F	Australia	Partnerships for Infrastructure (DFAT, Australia)				x	x
13	EW				x		x		
14	Handriyanti Diah Puspitarini	F	Indonesia	Institute for Essential Services Reform	x	x	x	x	x
15	Hean Veasna	M	Cambodia	Ministry of Minies and Energy / Deputy Director	x	x			x
16	Helen Locher	F	Australia	Helen Locher Consulting			x		x
17	Imre Gyuk	M	USA	US Department of Energy	x	x	x	x	x
18	Ingrid Carlier	F	Australia	Australian Water Project			x	x	x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
19	Jan Alam	M	USA	Pacific Northwest National Laboratory	x	x	x	x	x
20	Jansen Luis Luis Alexander, Ir. Dr.	M	Malaysia	Tenaga Nasional Bethad			x	x	x
21	Jeff Dagle	M	USA	Pacific Northwest National Laboratory			x		x
22	John Dore	M	Australia	DFAT		x			x
23	Jovian CHEUNG (HKC)	F	Hongkong, China	EMSD		x	x		x
24	Kamolphop Juntawach	M	Thailand	Electricity Generating Authority of Thailand	x	x	x	x	x
25	Kate Lazarus	F	Thailand	International Finance Corporation (IFC, part of the World Bank Group) / Senior Asia ESG Advisory Lead	x		x	x	x
26	Katharine Cross	F	Australia	Australian Water Project	x	x		x	x
27	Katie Purvis-Roberts	F	USA	Claremont McKenna, Pitzer, and Scripps Colleges	x	x	x	x	x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
28	Khairul Izzuddin Sulaiman	M	Malaysia	Sustainable Energy Development Authority	x	x	x	x	x
29	Khomgrit					x			
30	Krittiya Petsee	F	Thailand	Ministry of Energy of Thailand	x	x			x
31	Kullachai		Thailand	Electricity Generating Authority of Thailand	x	x	x	x	
32	lenovo				x	x			
33	Marc Goichot	M	Viet Nam	WWF / Lead Freshwater Asia Pacific	x				x
34	Mark L Bibeault	M	USA	Los Alamos National Laboratory	x	x	x	x	x
35	Martin Kennedy	M	Australia	GE Renewable Energy				x	x
36	Matthew Stocks	M	Australia	ANU		x			x
37	Chin MengChhorng	M	Cambodia	ELECTRICITÈ DU CAMBODGE / Officer at Hydro Technical Office	x	x	x		x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
38	Nguyen Minh Quang	M	Viet Nam	National Load Dispatch Center / EVN			x		x
39	Chy Chanrasmey	M	Cambodia	Ministry of Mines and Energy / Director	x				x
40	VY Ek Chin 黃奕進	M	Hongkong, China	Principal Energy Efficiency Advisor at Electrical and Mechanical Services Department (EMSD), Hong Kong, China Government	x		x		
41	NICOLA SAPORITI	M	Italy	International Finance Corporation (IFC, part of the World Bank Group) / Senior Investment Officer - Sector Specialist for hydropower. Water				x	x
42	Onanong Chotrasi	F	Thailand	DEDE	x	x	x	x	x
43	Palakorn Chanbanyong	M	Lao / Thailand	Mekong River Commission (MRC) / Sustainable Hydropower Specialist	x	x	x		x
44	PY				x				
45	Rinda				x				

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
46	Samuel Law	M	UK	IHA / Research and Policy Analyst	x				x
47	Saran Pansrisu	M	Thailand	Electricity Generating Authority of Thailand	x	x	x		x
48	Sataporn Limpatthamapanee	M	Thailand	Electricity Generating Authority of Thailand	x				x
49	Simon Kidston	M	Australia	Genex Power		x			x
50	Simon Krohn	M	Australia	Simon Krohn Consulting Pty Ltd	x	x	x		x
51	Son Davin		Cambodia	Ministry of Mines and Energy / Chief of Hydro-electric operation oversight office	x	x			x
52	Sorn Silinda	M	Cambodia	Ministry of Mines and Energy / Chief Office	x	x			x
53	Subin Netsawang	M	Thailand	Electricity Generating Authority of Thailand	x	x	x		x
54	Chin-Hsing CHIEN	M	Chinese Taipei	Taipower	x	x	x	x	x
55	Wen-Lung HUNG	M	Chinese Taipei	Taipower	x	x	x	x	x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
56	Wenta TSAI	M	Chinese Taipei	Taipower	x	x	x	x	x
57	Yi-Wen WANG	M	Chinese Taipei	Taipower	x	x	x	x	x
58	Hui-Chien CHUNG	M	Chinese Taipei	Taipower	x	x	x	x	x
59	Ing-Tsann CHANG	M	Chinese Taipei	Taipower	x	x	x	x	x
60	Pan-Chieh TSAO	M	Chinese Taipei	Taipower	x	x	x	x	x
61	Chih-Cheng CHUNG	M	Chinese Taipei	Taipower	x	x	x	x	x
62	Shumin HSU	F	Chinese Taipei	Taipower	x	x	x	x	x
63	Cheng-Hung CHUANG	M	Chinese Taipei	Taipower	x	x	x	x	x
64	Tien-Kuei LU	M	Chinese Taipei	Taipower	x	x	x	x	x
65	Yung-Chao CHIU	M	Chinese Taipei	Taipower	x	x	x	x	x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
66	Yung-Cheng KUO	M	Chinese Taipei	Taipower	x	x	x	x	x
67	Huan-Cheng WEN	M	Chinese Taipei	Taipower	x	x	x	x	x
68	Yi-Mei LIN	F	Chinese Taipei	Taipower	x	x	x	x	x
69	Tanaphat Rujirawat				x	x			
70	Thanun Hathaisete	M	Thailand	Electricity Generating Authority of Thailand	x				x
71	Thuong Nguyen Tien	M	Viet Nam	EVN	x				x
72	Tran Anh Thong	M	Viet Nam	National University of Singapore / Research fellow	x				x
73	Victor Martinez	M	Japan	Asia Pacific Energy Research Centre - APERC	x	x		x	x
74	Viswanathan, Vilayanur V	M	USA	Pacific Northwest National Laboratory			x		x
75	Weera Sriwarom	M	Thailand	DEDE	x	x	x	x	x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
76	Wunna Htun	M	Myanmar	Design Branch, Department of Hydropower Implementation / Deputy Director (Civil)	x				x
77	Xiaoyuan Fan	M	USA	Pacific Northwest National Laboratory			x		x
78	Yanisa LERTANANTRAKOON	F	Thailand	Ministry of Energy of Thailand	x	x			x
79	You Wei WONG	M	Malaysia	Sustainable Energy Development Authority	x	x	x	x	x
80	Zin Wai Soe	F	Myanmar	Staff Officer, Ministry of Natural Resources and Environmental Conservation	x				
	TA team								
1	Jamie Pittock	M	Australia	ANU	x	x	x	x	x
2	Daniel Gilfillan	M	Australia	ICEM	x	x	x	x	x

No	Name	Gender	Location	Organisation/Department/Position	Attendance				Formally registered
					2/2/2021	3/2/2021	4/2/2021	5/2/2021	
3	Luong Thi Quynh Mai	F	Hanoi	ICEM	x	x	x	x	x
4	Quy Dao	M	Hanoi	ICEM / IT	x	x	x	x	x

APPENDIX 2: AGENDA

Australian Eastern Summer Time

Time (Australia)	Tuesday 2nd February 2020	Wednesday 3rd February 2020	Thursday 4th February 2020	Friday 5th February 2020
Day & topic	**1. Introduction to PSH and status in the region**	**2. Opportunities to site PSH systems**	**3. Environmental and social standards for PSH**	**4. PSH in transition, financing, and concluding discussions**
9:00 to 10:00 Optional discussions* (to suit the Americas)		Optional bilateral / small group discussions with Dr. Gilfillan &/or Prof. Pittock.	Optional bilateral / small group workshop and discussions with Prof. A. Blakers & Assoc. Prof. M. Stocks.	Optional bilateral / small group discussions with case study presenters, Dr H. Locher, Ms. K. Lazarus, Dr J. Alam, Dr V. Viswanathan and Dr A. Somani.
12:30 Plenary session	a) Introduction to pumped storage hydropower. Prof. J. Pittock. b) International Forum on Pumped Storage Hydropower – Mr. S. Law	2. Opportunities to site PSH systems. Exploration of ANU global pumped hydro atlas. Prof. A. Blakers & Assoc. Prof. M. Stocks.	4. PSH Values and Costs: Experiences from the US. Dr J. Alam, Dr V. Viswanathan and Dr A. Somani.	6. a) Financing PSH projects. Mr. N. Saporiti b) PSH for transition to reliable, renewable energy supply, Mr. M. Kennedy
13:30	Break	Break	Break	Break
14:00 Plenary session	1. Role of PSH in future electricity systems. Discussion of draft status report on APEC + other Mekong economies. Dr. D. Gilfillan & Prof. J. Pittock.	3. Innovative developments: Kidston project, Genex Power, Australia. Mr. S. Kidston.	5. Environmental and social standards for PSH. Exploration of tools. Dr H. Locher and Ms. K. Lazarus.	7. Concluding discussions: a) key opportunities, b) actions to assist economies, c) next steps.
15:00	Break	Break	Break	Break
15:30 to 16:30 Optional discussions*	Optional bilateral / small group discussions with Dr. Gilfillan &/or Prof. Pittock.	Optional bilateral / small group workshop and discussions with Prof. A. Blakers & Assoc. Prof. M. Stocks.	Optional bilateral / small group discussions with case study presenters, Dr H. Locher and Ms. K. Lazarus	Optional bilateral discussions with case study presenters, PSH role in transition and financing projects. Mr Saporiti & Mr M. Kennedy.
18:00-19:30 Optional discussions*			Optional bilateral / small group discussions with case study presenter Dr. S. Sparkes.	

(to suit Asia and Oceania)				

- Core sessions with expert speakers are highlighted in green.
- Workshop participants can choose to book 10 minute bilateral or small group discussions* with expert presenters to explore the circumstances and opportunities for their economies (highlighted in purple). For example, this could be a short discussion on the use of key tools such as the sites atlas or sustainability assessment. These sessions are repeated so that different time zones can attend.

Times in local time zone

Time/Economy (Australia, AEDT)	Brunei Darussalam (BNT)	Canada (EST)	Chile (CLST)	People's Republic of China (CST)	Hong Kong, China (HKT)	Indonesia (WIB)	Japan (JST)	Republic of Korea (KST)	Malaysia (MYT)	Mexico (CST)
9am-10am - Optional discussions*	6am-7am	5pm-6pm	7pm-8pm	6am-7am	6am-7am	5am-6am	7am-8am	7am-8am	6am-7am	4pm-5pm
12:30:00 pm - Plenary session	9:30am-10:30am	8:30-9:30pm	10:30-11:30pm	9:30am-10:30am	9:30am-10:30am	8:30am-9:30am	10:30am-11:30am	10:30am-11:30am	9:30am-10:30am	7:30pm-8:30pm
1:30pm Break										
2pm - plenary session	11am-12pm	10pm-11pm	12am-1am	11am-12pm	11am-12pm	10am-11am	12pm-1pm	12pm-1pm	11am-12pm	9pm-10pm
3pm Break										
3:30 pm to 4:30pm - Optional discussions*	12:30pm-1:30pm	11:30pm-12:30am	1:30am-2:30am	12:30pm-1:30pm	12:30pm-1:30pm	11:30am-12:30pm	1:30pm-2:30pm	1:30pm-2:30pm	12:30pm-1:30pm	10:30pm-11:30pm
6pm-7pm - Optional discussions*	3pm-4pm	2am-3am	4am-5am	3pm-4pm	3pm-4pm	2pm-3pm	4pm-5pm	4pm-5pm	3pm-4pm	1am-2am

Time/Economy (Australia, AEDT)	New Zealand (NZDT)	Papua New Guinea (PGT)	Peru (PET)	The Philippines (PHST)	Russia (MSK)	Singapore (SGT))	Chinese Taipei (CST)	Thailand (ICT)	The United States (EST)	Viet Nam (ICT)
9am-10am - Optional discussions*	11am-12pm	8am-9am	5pm-6pm	6am-7am	1am-2am	6am-7am	6am-7am	5am-6am	5pm-6pm	5am-6am
12:30:00 pm - Plenary session	2:30pm-3:30pm	11:30am-12:30pm	8:30pm-9:30pm	9:30am-10:30am	4:30pm-5:30am	9:30am-10:30am	9:30am-10:30am	8:30am-9:30am	8:30pm-9:30pm	8:30am-9:30am
1:30pm Break										
2pm - plenary session	4pm-5pm	1pm-2pm	10pm-11pm	11am-12pm	6am-7am	11am-12pm	11am-12pm	10am-11am	10pm-11pm	10am-11am

3pm Break										
3:30 pm to 4:30pm - Optional discussions*	5:30pm-6:30pm	2:30pm-3:30pm	11:30pm-12:30am	12:30pm-1:30pm	7:30am-8:30am	12:30pm-1:30pm	12:30pm-1:30pm	11:30am-12:30pm	11:30pm-12:30am	11:30am-12:30pm
6pm-7pm - Optional discussions*	8pm-9pm	5pm-6pm	2am-3am	3pm-4pm	10am-11am	3pm-4pm	3pm-4pm	2pm-3pm	2am-3am	2pm-3pm

APPENDIX 3: PRESENTATIONS

Presentation 1: Introduction - Prof. Jamie Pittock

APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply, online, 2-5 February 2021

Introduction

Prof. Jamie Pittock – Project Overseer
Fenner School of Environment & Society
The Australian National University
jamie.pittock@anu.edu.au

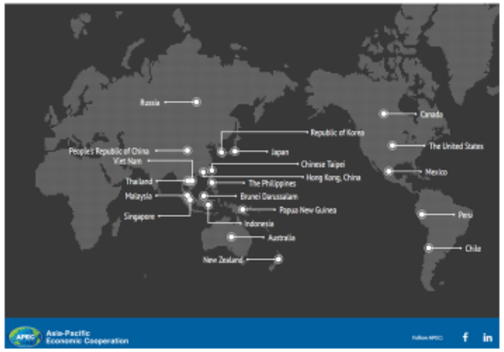
Asia-Pacific Economic Cooperation

Australian National University

THE AUSTRALIAN WATER PARTNERSHIP

APEC Energy Working Group

- APEC EWG “seeks to maximize the energy sector's contribution to the APEC region's economic and social well-being, while mitigating the environmental effects of energy supply and use”
- APEC 21 economies = ~60% of world energy demand



Australian Aid | THE AUSTRALIAN WATER PARTNERSHIP

Australian Mekong Water Facility

An Australian Government program administered by the Australian Water Partnership “to further enhance existing water-related partnerships with the governments of the Mekong region.” The objectives include:

- strengthening the capacity and resilience of governments to manage water and respond to challenges posed by climate change; and
- promoting higher standards for water infrastructure and water governance in the region in support of greater water, food and energy security

Greater Mekong Sub-region cross border power transmission lines

Asia-Pacific Economic Cooperation | Australian Aid | THE AUSTRALIAN WATER PARTNERSHIP | Australian National University

APEC renewable energy target

APEC Energy Demand and Supply Outlook (7th Edition) in 2019:

- energy demand of APEC economies by 2050 will increase by 21% above 2016 levels;
- energy demand decoupled from economic growth;
- over 80% of the region’s 2050 primary energy demand would be met by fossil fuels under business-as-usual (BAU).
- carbon dioxide emissions from fuel combustion are projected to rise 6% under BAU.

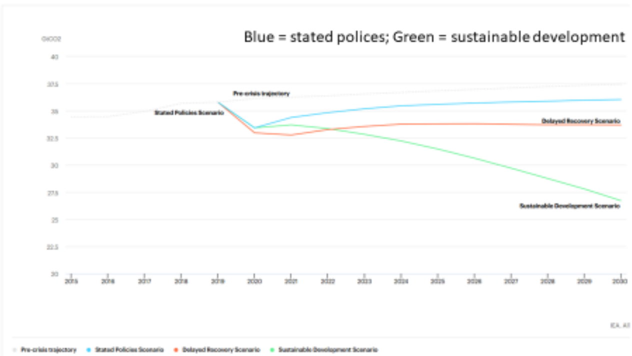
The report shows that APEC is:

- on track to reduce energy intensity by 45% by 2029—six years ahead of target; but
- unable to achieve the APEC target goal of doubling the share of renewables in the energy mix from 2010 to 2030, in a BAU scenario.

Clean energy to address climate change

International Energy Agency, Energy sector and industrial process CO2 emissions by recovery trajectory, IEA, Paris https://www.iea.org/data-and-statistics/charts/energy-sector-and-industrial-process-co2-emissions-by-recovery-trajectory

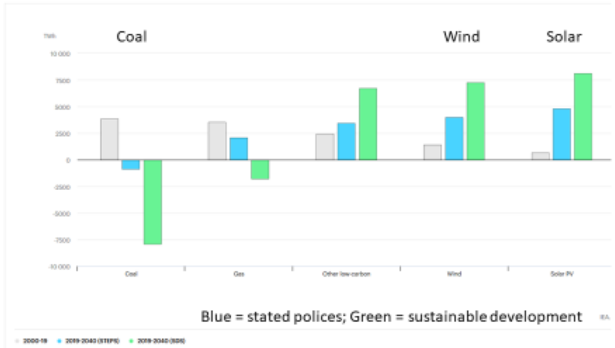
Energy sector and industrial process CO2 emissions by recovery trajectory



Growth of solar and wind requires storage

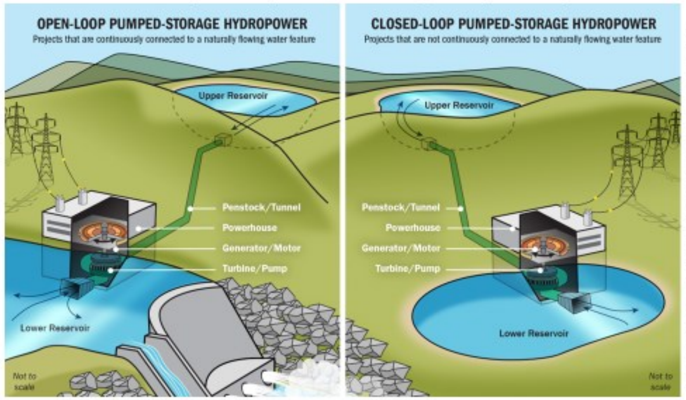
International Energy Agency, Change in global electricity generation by source and scenario, 2000-2040, IEA, Paris https://www.iea.org/data-and-statistics/charts/change-in-global-electricity-generation-by-source-and-scenario-2000-2040-2

Change in global electricity generation by source and scenario, 2000-2040



Asia-Pacific Economic Cooperation | Australian Aid | The Australian Water Partnership | Australian National University

What is pumped storage hydropower?



https://www.energy.gov/eere/water/pumped-storage-hydropower

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Why pumped storage hydropower?

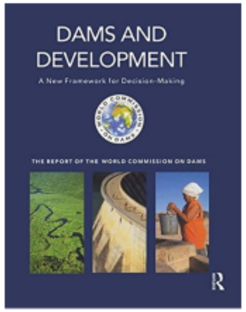
- ~95% of existing global electricity storage capacity
- ~70-80% round trip energy efficiency
- Many possible sites, e.g. reuse mines, existing reservoirs
- Off river sites with lower environmental impacts
- Small areas of land needed > displace fewer people
- Reduce impacts of low inflows on hydro schemes

Tumut 3 pumped storage power station, 1,500 MW capacity, Australia © J Pittock

Challenges with hydropower projects

Extensive criticisms over decades:

- Roads and transmission lines facilitate environmental impacts
- Impacts on rivers and fisheries
- Displacement of people
- Poor benefit sharing
- Time and cost overruns
- Exaggerated benefits
- Corruption



World Commission on Dams 2000

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PSH topics that this workshop will cover:

1. What is it?
2. What are the benefits, costs and risks?
3. Where could PSH be built?
4. What tools are available to minimize environmental and social impacts and maximize the benefits?
5. Examples of projects in APEC economies
6. Status of electricity storage and renewable energy targets in APEC + Mekong economies
7. How do projects integrate with power grids?
8. Project financing
9. Further information

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Workshop objectives

- APEC projects: "help translate the policy directions of APEC Economic Leaders and Ministers into actions and help create tangible benefits for people living in the Asia-Pacific region."
- APEC goal for doubling the share of renewables in the energy mix by 2030.

Objectives:

1. Capacity-building.
2. Opportunities.
3. Environmental and social sustainability protocols.
4. Networking.

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How we will work: 2-5 February 2021

- Presentations are pre-recorded for participants to watch at convenient times
- Each day there are 1-2 hours of live plenary discussions with that day's presenters
- Participants can book an additional 10 minute bilateral discussion time with expert presenters

- Project overseer: Prof. Jamie Pittock, The Australian National University, jamie.pittock@anu.edu.au
- Project contractor: Dr Daniel Gilfillan danielg.icem@gmail.com and Ms Mai Quynh Luong, International Centre for Environmental Management (ICEM)

The draft background paper sent to you:

- Background paper prepared to inform workshop discussions
- Includes a synthesis for each of the 21 APEC + 3 Mekong economies
- Covers current and planned
  - Renewable electricity generation
  - Energy storage
  - Grid reliability
  - Cross-border transmission
- Desk top review of available data in English – gaps are likely
- For discussion 2nd February 2021
- Corrections and revisions welcome on the provided template
- Will be revised for publication as an APEC technical report

Information and tools to be discussed:

- Workshop draft background paper
- Global pumped hydro atlas
- Hydropower Sustainability Assessment Protocol
- IFC Performance Standards on Environmental and Social Sustainability
- International Forum on Pumped Storage Hydropower
- Others?

Tumut 3 pumped storage power station, 1,500 MW capacity, Australia © J Pittock

Concluding session – next steps?

Final plenary session on Friday 5th February is to:

- Summarise key discussions
- List information and tools of use to APEC+ economies
- Consider any recommendations to the APEC Energy Working Group for follow up activities
- Revisions to the background paper for an APEC technical report
- Policy brief

Tumut 3 pumped storage power station, 1,500 MW capacity, Australia © J Pittock

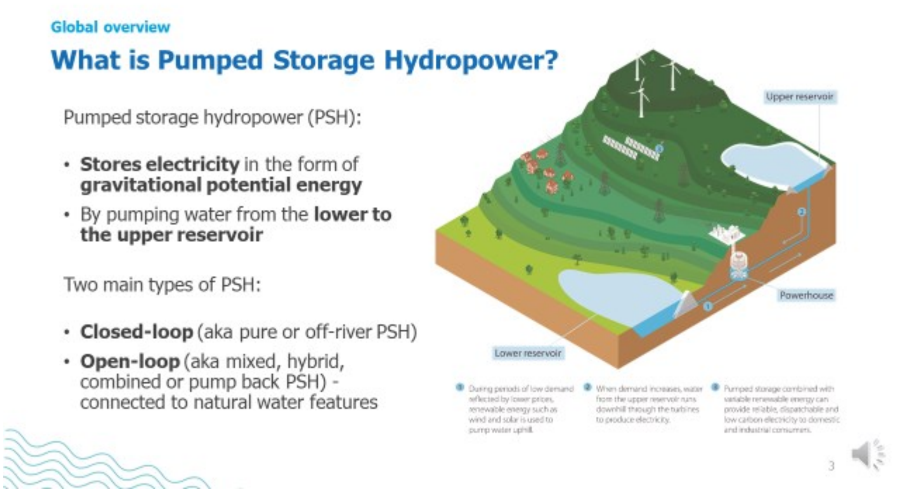
Your feedback opportunities

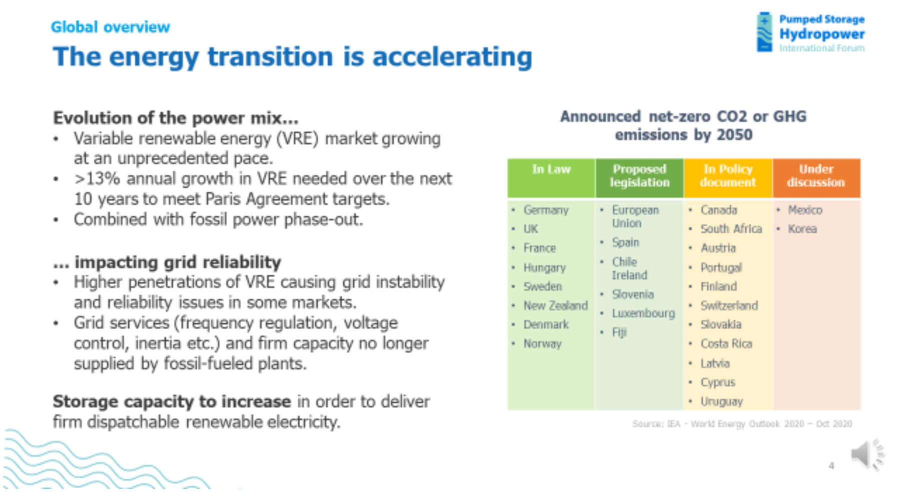
- In daily plenary sessions
- You will be invited to provide feedback anonymously on line each day
- There is a follow up APEC project participant survey
- We would like to ask you again in 6-12 months which (if any) information that you found useful

Email:

- Project overseer: Prof. Jamie Pittock jamie.pittock@anu.edu.au
- Project contractor: Dr Daniel Gilfillan danielg.icem@gmail.com

Presentation 2: PSH for transition to reliable, renewable energy - Samuel Law





Global overview

Need for long-duration storage

Pumped Storage Hydropower International Forum

PSH currently accounts for over 90% of storage capacity and stored energy

PSH offers a cost-effective way to provide **large-scale balancing and grid services** through:

- **Storage** of greater quantities of immediately available renewable electricity.
- Providing greater **flexibility and stability** to the network.

The current storage volume of PSH stations is **at least 9,000 GWh**.

PSH installed capacity
Source: IHA

325 GW of PSH required by 2050* to enable smooth energy transition

Stated PSH targets, aims or needs

- **India - 35 GW** needed by 2030, focus on PSH.
- **China** - New 14th Five-Year Plan (2020-2025) to be released in 2021. **~50 GW** of PSH under construction.
- **NSW (Australia) - 2 GW** needed by 2030, PSH focus.**
- **Great Britain** - estimates that GB could need **at least 30 GW** of energy storage to meet their 2050 climate goals – ten times current capacity.
- **California** - Regulator has identified the need for **1 GW of PSH**, or other long-duration storage with similar attributes, by 2026.

* Source: IRENA
** Plus Snowy 2.0

Global overview

PSH development under pressure

Pumped Storage Hydropower International Forum

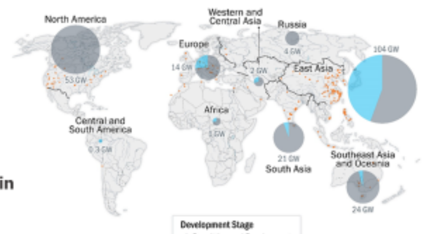
Recent developments mainly **driven by China**. Other projects recently been commissioned or still under construction in Europe, Asia, India, Israel, Australia, Morocco, Egypt and the UAE.

Recent development **led by government/public utilities**.

Very **little private sector-led or financed PSH**.

- ➢ Need to foster investment in new projects **both in regulated and deregulated markets**
- ➢ Need for new markets and reforming existing ancillary markets to appropriately compensate **existing PSH assets**

PSH project development pipeline by region and development stage



Note: This map only includes projects ≥ 10 MW.

Oak Ridge National Laboratory

Source: ORNL Hydropower Market Report team

Global overview

Challenges facing PSH development

Pumped Storage Hydropower International Forum

- **Lack of understanding** about the technology, its capabilities, sustainability profile and innovative new developments – often left out of discussions about energy storage.
- **Difficulty in financing** new PSH projects and operating existing ones profitably – uncertain revenues from energy arbitrage and many services are not appropriately remunerated.
- **Insufficient incentives** in many markets despite the agreed need for long-duration storage.

El Hierro PSH, Spain
Source: Gorona del Viento

International Forum on Pumped Storage Hydropower

Pumped Storage Hydropower International Forum

Steering Committee
Gov'ts & IFIs

Partners
Industry, Academia & NGOs

Secretariat
iha

A government-led multi-stakeholder platform to help address the key challenges facing pumped storage development

This year-long initiative brings together:

- **11 governments**, chaired by the U.S. Department of Energy
- **5 multilateral development banks** and the International Renewable Energy Agency (IRENA)
- Over **70 partner organisations** from industry, finance community, academia and NGOs

IHA is the secretariat of the Forum.

International Forum on Pumped Storage Hydropower

Steering Committee Members

Partners

Forum Activities & Working Groups

The Forum was launched on 3 November with **Former Prime Minister of Australia, Hon. Malcolm Turnbull** delivering keynote address.

Attended by over 200 high-level participants from some 40 countries with an ambitious, outcome orientated work programme covering:

Policy & Market Frameworks

Sustainability

Capabilities, Costs & Innovation

10

Capabilities, Costs & Innovation - Overview

Capabilities, Costs & Innovation Working Group

Lead Partner: **Voith Hydro**

This Working Group will raise the awareness of PSH by undertaking several initiatives focusing on promoting its critical role in the energy transition.

It will focus on **comparing PSH** with other sources of system **flexibility**, further investigation of **potential sites** and highlighting the latest **technological innovations**.

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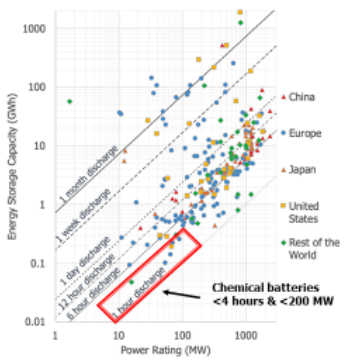
Capabilities, Costs & Innovation - Overview

High capacity, long duration storage

- This plot visualises the estimated discharge durations relative to installed capacity and energy storage capacity for some 250 pumped storage stations currently in operation.
- The majority of pumped storage stations have a discharge duration longer than 6 hours, and some are capable of seasonal storage.



Source: IHA

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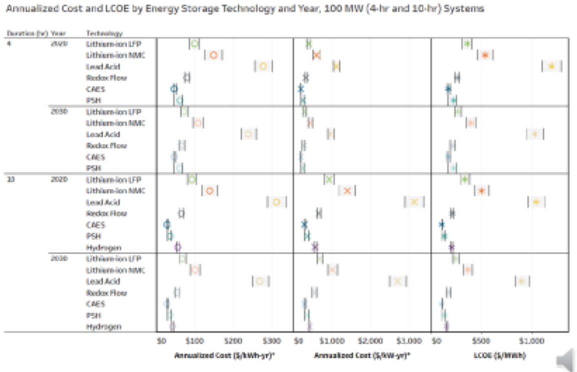
Key capabilities & characteristics of PSH

PSH represents a **mature, efficient, and cost-effective** option in terms of **$ per kWh of stored energy**.

100 MW, 10-hour energy storage cost estimate:

PSH:	$262/kWh
li-ion battery:	$356/kWh



Source: US DOE

Global potential for PSH development

2019 ANU study:
600,000 sites identified for potential off-river PSH development

Source: IHA & ANU

Innovations in PSH

Retrofitting disused mines

- **Utilising existing infrastructure** to reduce costs & environmental impacts. Example: 250 MW Kidston project

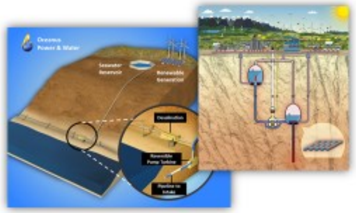
Seawater PSH + Desalination

- **24/7 freshwater generation** with no external power source
- **Low levelised cost** for energy storage and water
- **Lower environmental impacts** with seawater management system & reduce carbon intensity of clean water production

Thermal Underground PSH

Water is the common energy carrier for **both electricity & thermal storage**

- **95% energy efficiency**: Synergy effects
- CAPEX breakthrough, low LCOS
- New business models, more flexibility



Sustainability Working Group

Lead Partner: **EDF Hydro**

- This Working Group aims to promote and deepen the wider sector's understanding on pumped storage's **sustainability profile**.
- It will focus on both the benefits and impacts of development by testing PSH projects against **existing sustainability assessments** and assessing **value creation for local communities**.

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Environmental impacts

Global Warming Potential (GWP)

Compared for the lifetime of 100 years:

- BESS: 2.6 million t CO2-equivalent
- PSH: 1.1 million t CO2- equivalent

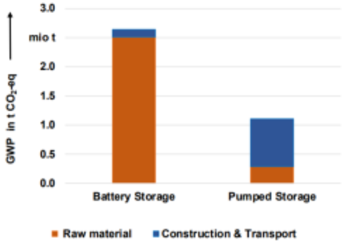


Figure 8: GWP of the two technologies

Source: Voith Hydro & RWTH Aachen University

Hydropower Sustainability Tools

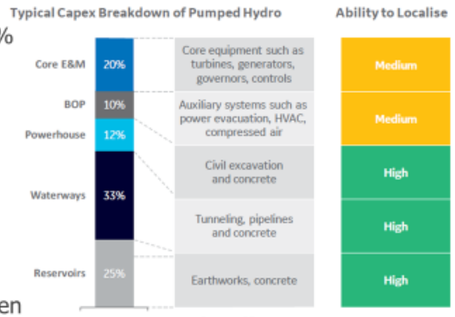
- Testing PSH against internationally recognised hydropower sustainability tools

Hydropower Sustainability Assessment Protocol

Pumped Storage Hydropower International Forum

Economic impacts

- Unlike batteries, **PSH includes major civil components**, >70% of the total project capital expenditures (CapEx).
- **Money can flow directly into hiring local workers and equipment** and procuring key materials such as cement.
- This also **reduce reliance on imported raw materials** as seen in chemical battery storage.



Source: GE

Pumped Storage Hydropower International Forum

Policy and Market Frameworks Working Group

Lead Partner: **GE Renewable Energy**

- This Working Group will explore the various services and markets to highlight the current investment barriers but also emerging opportunities for PSH development.
- A key focus of the group will be developing country and regional specific policy recommendations for government decision makers and regulators that de-risk development.

Pumped Storage Hydropower International Forum

Government Policies and Programs

- Incentives and Mandates
  - China's PSH mandate of 50 GW in 13th Five Year Plan.
  - Indian government has identified a need for a significant expansion in power system flexibility
- Capacity Markets
  - **Capacity market mechanism** designed to help ensure that electricity supply continues to meet demand as more volatile and unpredictable VREs come online.

Policy & Market Frameworks - Overview

Other Sectors and Market Configurations

- Transmission: **Cap and Floor Mechanism**
  - The mechanism supports this development where otherwise **secure financing was not available due to uncertainty of long-term revenues**.
  - A rate recovery floor, that is a **minimum return guaranteed** to receive from customers through regulated transmission rates.
  - A cap, or a **maximum return** projects can receive, permitting market participation while protecting ratepayers and preventing windfall profits for the developer.

- PSH as a System Resource: the Middle East and North Africa
  - Egypt is working to diversify its energy mix and develop 10 GW of new solar and wind capacity by 2022, having experienced recent power shortfalls.
  - It has a primarily state-owned electric system that is moving toward more private providers.
  - The Attaqa Mountain PSH plant is a 2.4 GW project will be the first PSH plant in the country.

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Policy & Market Frameworks - Overview

Energy System Structural Insights

- Market Designs (particularly Ancillary Services)
  - A **six-year contract** will permit one of the four turbines at Drax's 440 MW Cruachan pumped storage station to be used to provide flexibility support services to the grid, specifically, **inertia and reactive power**.
  - This contract is a part of National Grid Electricity System Operator's System Stability Pathfinder Tender.

  - Other jurisdictions have been to consider more responsive market products
    - Ireland: market for synchronous inertial response and fast frequency response
    - Australia: inertia and other fast response
    - California: ramping product to address evening solar ramps
    - Texas: primary frequency response and fast frequency response

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Policy & Market Frameworks - Overview

Energy System Structural Insights

Market Designs: 'Virtual Storage' Hedge Contract in Australia

- Deal signed by Hydro Tasmania and two buyers – Macquarie Group and ERM Power
- A set spread between the charge and discharge price for energy storage.
- The same MWhs for charge/discharge legs.
- Transaction price is the agreed price spread between bought and sold legs.
  - De-risking energy arbitrage revenue.
  - Allowing revenue options in the forward market.

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International Forum on Pumped Storage Hydropower

Working Groups

Policy & Market Frameworks
- Global overview & position paper
- 10 regional/country papers
- Policy & market recommendations

Sustainability
- Life Cycle Assessment (LCA)
  Use of Sustainability Tools on PSH projects
- Value creation model for local communities

Capabilities, Costs & Innovation
- Comparisons with other sources of system flex.
- PSH potential mapping
- Innovative PSH configurations & uses

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International Forum on Pumped Storage Hydropower

Thank you!

Pumped Storage Hydropower International Forum

Please visit:
https://pumped-storage-forum.hydropower.org/

To participate in the Forum, please contact:

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International Hydropower Association
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f: +44 20 8643 5600
e: samuel.law@hydropower.org

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Presentation 3: Background on PSH in 21 APEC+3 Mekong Economies – Dr. Daniel Gilfillan

APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply, online, 2-5 February 2021

Draft Report:
PSH in 21 APEC + 3 Mekong Economies

Dr Daniel Gilfillan – Project Consultant
International Centre for Environmental Management (ICEM)
danielg.icem@gmail.com

Asia-Pacific Economic Cooperation

icem Climate Change | Biodiversity Water | Integrated Assessments

THE AUSTRALIAN WATER PARTNERSHIP

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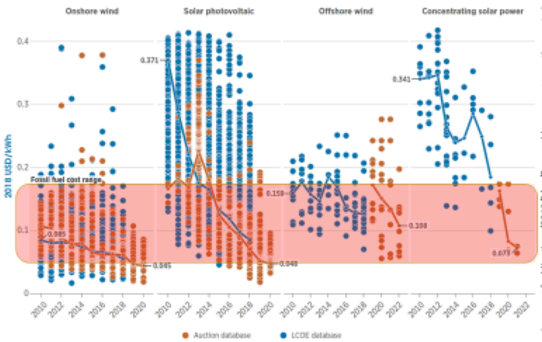
Presentation Structure

1. Drivers of the need for Electrical Energy Storage (EES)
2. Different EES technologies and their characteristics
3. Pumped Storage Hydropower (PSH) Overview
4. PSH in 21 APEC + 3 Mekong Economies
5. Conclusions

Electrical Energy Storage Drivers

1. Reducing cost of electricity production from renewables

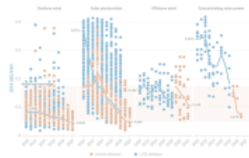
- Cost range for fossil-fuel based electricity production (static over time)
- Declining costs of renewable generation.
  Costs now below fossil fuel based generation (onshore wind and solar), and competitive (offshore wind and concentrating solar)



https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

Electrical Energy Storage Drivers

1. Reducing cost of electricity production from renewables
2. Agreements to reduce use of fossil fuel based electricity generation (e.g. Paris Agreement)
   - All economies considered here have stated targets targets for growth in renewables
   - Some information ***found*** for targets is out of date → e.g. Hong Kong, China has 2012 target and Peru has 2013 target
   - Targets are not easily comparable →
     - Some stated in Watts (MW or GW)
     - Some stated in Watt hours (GWh)
     - Some stated as percentage of capacity
     - Some stated as percentage of produced electricity



Comparing Different Electrical Energy Storage Systems (ESS)

Technology	Brief description
Pumped Storage Hydropower	Water is pumped to an upper reservoir and is then available to generate power
Flywheel Energy Storage	Excess power stored mechanically as rotation energy – useful for releasing short bursts of high power energy
Chemical batteries (Li-ion, NaS etc...)	Excess power used to stimulate electron flow to store power chemically, which can then be released on demand
Compressed Air Energy Storage	Air is compressed and stored, and can then be released to a combustor in a gas turbine to generate power

https://www.ema.gov.sg/cmsmedia/Final%20Determination%20Paper%20-%20ESS%20vf.pdf

Comparing Different Electrical Energy Storage Systems (ESS)

Technology	Capital Cost (USD/kW)	Flexibility: Discharge time	Useful Life (years)	Useful Life (cycles)	Operating and Maintenance costs
Pumped Hydro	600 to 2000	Flexible to 48 hours +	40 to 60 years	-	$3/kW/year
Flywheel Energy Storage	250 to 300	Seconds to minutes	15 years	20,000	$.004/kW/year
Lithium-Ion (Li-Ion) Battery	1200 to 4000	Minutes to hours	5 to 15	1,000	-
Sodium-Sulfur (NaS)	1000 to 3000	Seconds to hours	10 to 15	2,500	$80/kW/year
Compressed Air Storage (CAES)	400 to 800	30 to 40 minutes	20 to 40	-	$19/kW/year
Lead-Acid (Pb-Acid)	300 to 600	Seconds to hours	5 to 15	500 to 1000	$50/kW/year
Vanadium Redox Flow Battery (VRFB)	600 to 1500	Seconds to hours	5 to 10 years	12,000	$70/kW/year

https://www. eubusinessinjapan. eu/sites/default/files/energy_storage_landscape_in_japan. pdf, and
https://aemo.com.au/-/media/files/major-publications/isp/2020/final-2020-integrated-system-plan.pdf?la=en&hash=6BCC72F9535B8E5715216F8ECDB4451C

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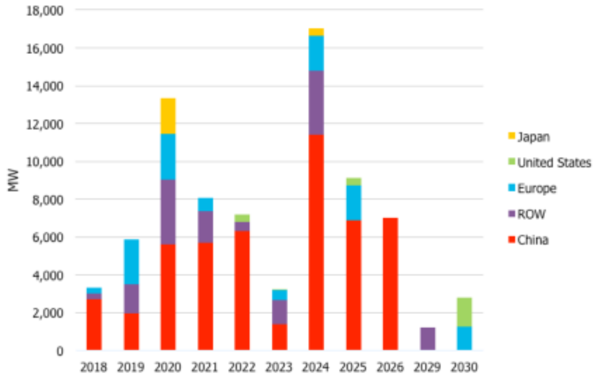
Projected global PSH growth 2018 - 2030



https://www.hydropower.org/sites/default/files/publications-docs/2020_hydropower_status_report.pdf

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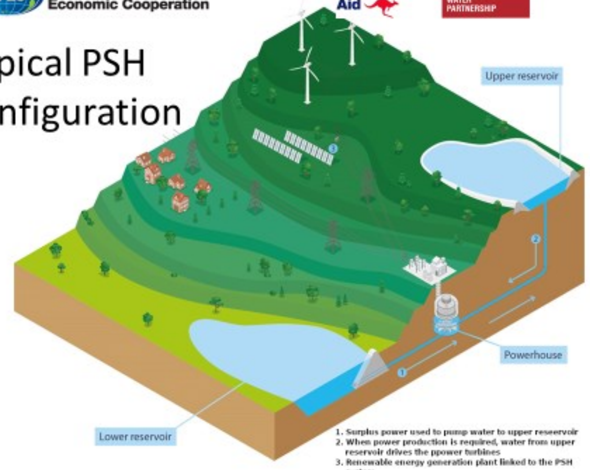
Typical PSH configuration



1. Surplus power used to pump water to upper reseervoir
2. When power production is required, water from upper reservoir drives the ppower turbines
3. Renewable energy generation plant linked to the PSH system

https://www.hydropower.org/types-of-hydropower

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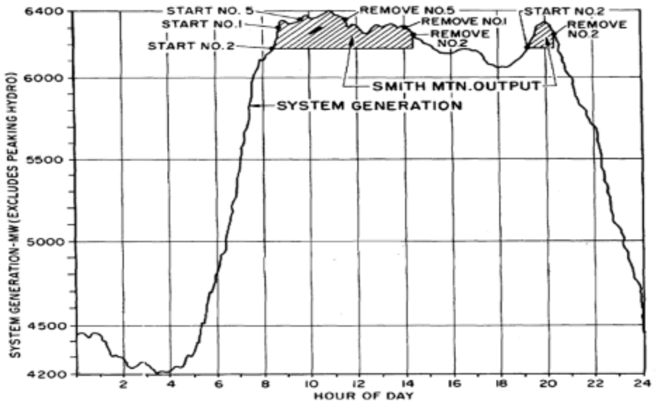
Example of PSH providing peaking generation



https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=4073062&casa_token=22maU3EI7CAAAAAA:DgdZsMn2e3r8BYCCnbWFqoAd§jszUW2N0P5_QrdtLx2D3WOKd2bB-Uiw75ma7YYFHIy2P4W6NY&tag=1 (1966)

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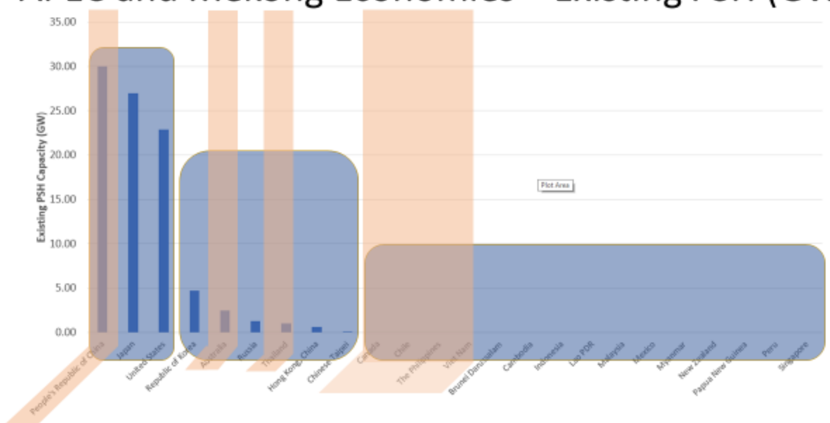
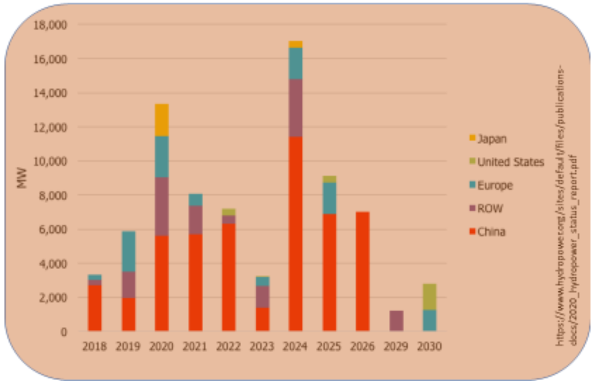
APEC and Mekong Economies – Existing PSH (GW)



Economies with established PSH systems

- Japan includes energy storage an explicit grid component
- Japan has more than 25 existing PSH systems with a combined capacity of approximately 27GW

- The People's Republic of China (PRC) currently has approximately 30GW of installed PSH capacity
- The PRC is projected to more than double it's installed PSH capacity by 2030 to around 75GW



Economies with established PSH systems

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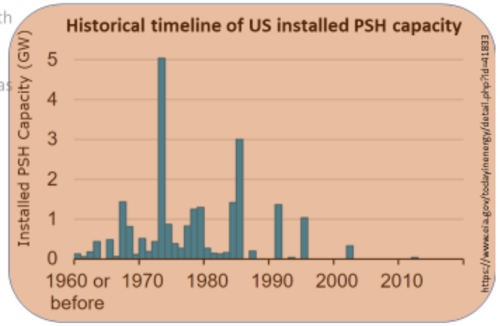
- The People's Republic of China (PRC) currently has approximately 30GW of installed PSH capacity
- The PRC is projected to more than double it's installed PSH capacity by 2030 to around 75GW

- The United States (US): 8.6% of electricity generation from non-hydropower renewables in 2019
- 97% of electrical energy storage in the US is PSH
- Most PSH constructed in the US in the 1960s, 1970s & 1980s



Economies with some PSH investment

Country	PSH summary
Republic of Korea (ROK)	• Has 4.7 GW of installed PSH capacity, but there is a lack of evidence of further planning for electricity storage
Australia	• 3 existing PSH systems (2.5GW installed capacity) • 3 PSH systems in advanced planning stages (approx. 4 GW planned installed capacity)
Russia	• First PSH system installed in 1987 (1.2 GW), with only one additional PSH system installed since then (140MW) • Russia has installed battery storage with up to 8MWh of storage capacity
Thailand	• Has 1GW of installed PSH capacity with plans to add another 800MW
Hong Kong, China	• HK has rights to half the output of the 600MW Phase I of Guangzhou PSH station • HK acknowledges the need for additional storage because of variability of renewable electricity production
Chinese Taipei	• Has 2.6GW of installed PSH • Also targeting geothermal storage to support renewables growth

Economies planning to install PSH

Country	PSH summary
Canada	• Has demonstration PSH plus 2GW of PSH under development across 5 sites
Chile	• Plans for a 300MW PSH system using the Pacific Ocean as the lower reservoir. The PSH system will be linked to a neighbouring PV Solar array. Target completion date is 2025
The Philippines	• Currently has 1GW of PSH under construction • Government approvals complete for another 120MW PSH project
Viet Nam	• Economic viability of PSH beyond 1.5GW of capacity is uncertain • First PSH system in Viet Nam is projected for completion in 2028 with 1.2GW of capacity

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PSH potential in remaining economies

Country	PSH summary
Brunei Darussalam	• Lack of potential for PSH, however neighbouring economies have untapped potential
Cambodia	• Some PSH potential, however the power development master plan prioritises thermal power stations
Indonesia	• Good potential for PSH
Lao PDR	• Economic rationale for PSH has not been well explored despite significant conventional hydropower
Malaysia	• Has potential for PSH
Mexico	• Good potential for PSH
Myanmar	• Reasonable PSH potential
New Zealand	• Four PSH sites have been identified, however the economic case of development is still being debated
Papua New Guinea	• Good potential for PSH
Peru	• Peru's mountainous terrain is well suited to the development of PSH
Singapore	• Lack of potential for PSH, however neighbouring economies have untapped potential

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Conclusions

1	Range of Experiences with PSH	• PRC, Japan and the US with large installed capacity
		• ROK, Canada etc… with modest investment
		• Cambodia, Lao PDR, Peru etc… have potential for PSH in the future
2	Potential for PSH	• 21 of 24 economies considered in the Draft Report on PSH in 21 APEC + 3 Mekong Economies have significant untapped potential for PSH
		• The other three (3) economies are Brunei Darussalam, Hong Kong (China), and Singapore. These three economies all have transmission links to countries with PSH potential
3	Rapid Growth in VRE	• EES is becoming increasingly important
		• Different EES technologies have different characteristics, suitable for different purposes: • Battery: Frequency control and ramping • Large battery/small PSH: Intra-day shifting (e.g. produce during day, use during evening) • Larger PSH: Seasonal smoothing and "VRE droughts"

Presentation 4: A global atlas of off-river pumped hydro storage – Assoc. Prof. Matt Stocks

Australian National University

A Global Atlas of Off-River Pumped Hydro Storage

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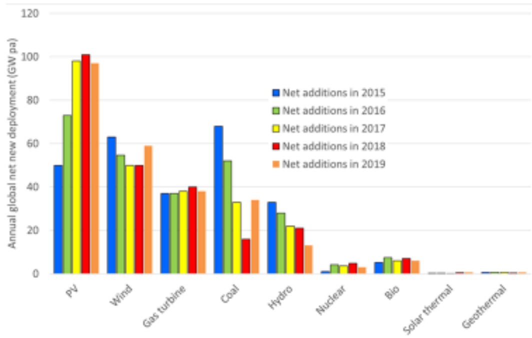
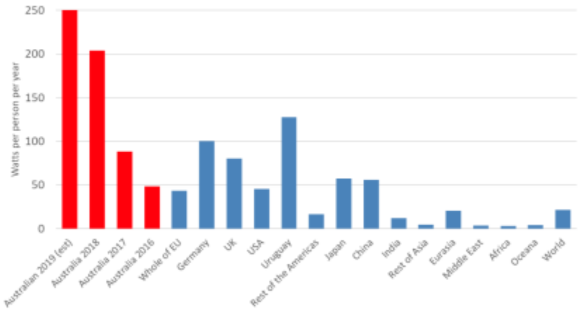
College of Engineering and Computer Science
Australian National University
https://re100.anu.edu.au

Australian National University

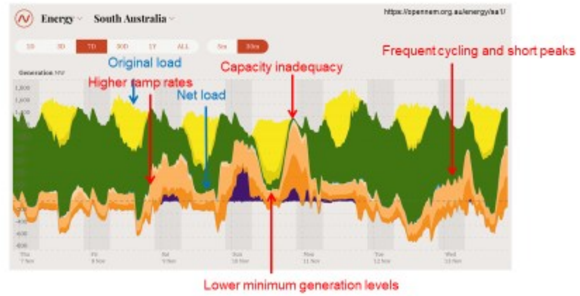
Solar PV and wind leading world's new generation capacity



World per capita renewable installations



Challenge: intermittency



OpenNEM (2019)

Challenge: intermittency

Stabilise variable renewable electricity

- Technical diversity
  - 90% PV and wind (+ existing hydro & biomass)
- Wide geographical dispersion (million km^2) hugely reduces storage
  - Smoothing-out local weather
- Demand management
  - Shift loads from night to day, interruptible loads
- Mass storage
  - Pumped hydro: 97% of all storage
  - Advanced batteries

Challenge: intermittency

OpenNEM (2019)

Challenge: Intermittency

Australian National University

OpenNEM (2019)

Global Pumped hydro atlas

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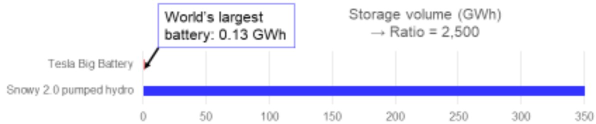
- Off-the-shelf, lowest-cost technology
  - 180 GW already installed
  - No arm-waving about large future cost reductions
- 100-1,000 times larger storage than batteries



- However, location driven by local topography
- Concerns regarding large-scale hydro development

Closed loop off-river pumped hydro

Australian National University

PHES Site searching

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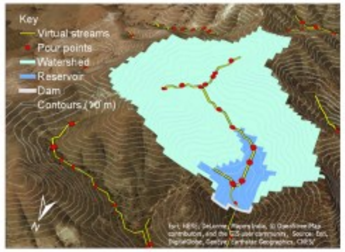
Identify reservoirs locations
- Model watershed
- Simulate 5 -100m dams

Pair reservoirs
- 100-800m head
- Adjust both dam heights for storage target (e.g. 5 GWh)

Apply cost model
- "A" to "E" ranking (or reject)

Key information recorded
- Reservoir volume and area, dam line and volume, reservoir shape file, etc



Cost model

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Model developed with international engineering consultancies (B&V/GHD) for Australian Government funded project

- Reservoir pair
- Water conveyance (~~penstock or~~ tunnel)
- Power house (pump/turbine, generator, switchyard)
- ~~Services (roads, water, transmission)~~

Key relationships (head, power, separation, dam volume) used for global search ranking

Reservoir Pair

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- Clay core rockfill dam 10-100 m high
  - Material borrowed from reservoir
- 3:1 batter slope
- 2 m deep foundation excavation
- Crest width: 8 m
- Concrete spillway designed to cope with flood or pumping (whichever is larger)

Conveyance - Powerhouse - Switchyard

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- Tunnel
  - Vertical shaft and horizontal tunnels
- Excavated powerhouse.
  - Machine hall, transformer hall, electrical equipment tunnels, access/construction tunnels, cable and ventilation tunnel
  - Excavation, stabilization (shotcrete, rock bolts) and pavement
- Twin pump-turbine/motor-generator, variable speed.
- Inlet valves, transformers, cranes, ancillary mechanical and electrical equipment, switchyard

>600,000 unique sites with 23,000 TWh of storage

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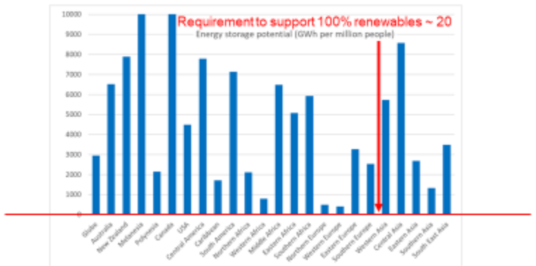
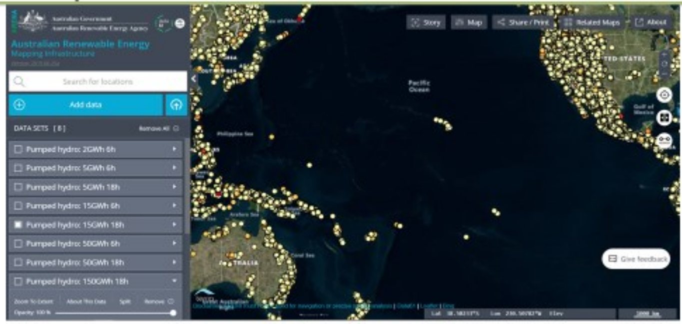


Open online access to full database

Australian National University



http://re100.eng.anu.edu.au/global
https://nationalmap.gov.au/renewables/#share=s-oDPMo1jDBBtwBNhD

Significant pumped hydro resource across APEC

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Zooming in: Thailand

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Zooming in: Phetchabun region

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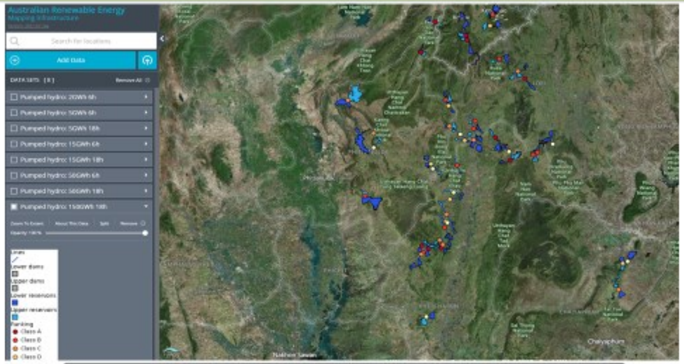


3D visualisation with key info pop-ups

Australian pumped hydro proposals

Summary

- Variable renewables growing rapidly
- Pumped hydro well-placed to support transition
- Global off-river atlas developed
  - 600,000 sites with >23,000TWh storage
  - Full visualisation from global to local scale

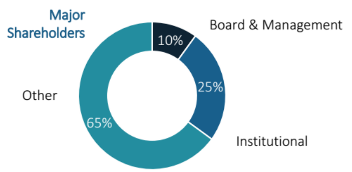
Presentation 5: Kidston Stage 2_250MW Pumped Hydro Project - Simon Kidston, Genex Power

The Climate Council Case Study: Kidston

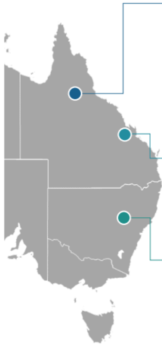
Genex at a glance

Genex aims to be Australia's leading listed renewable energy generation and storage company

ASX code:	GNX
Shares on issue:	511.5M
Market cap (20.01.2021):	$130M
Cash (31.12.2020)[1]:	$41M
Favourable Tax Ruling[2]:	$39.5M



1. Includes drawn debt facilities for JSP construction.
2. Refer to the Company's ASX announcement dated 4 October 2016.



Kidston Clean Energy Hub

Stage 1: 50MW Kidston Solar Project

Stage 2: 250MW Kidston Pumped Storage Hydro Project

Stage 3: 150MW Kidston Wind Project & Kidston Solar Expansion

Bouldercombe Battery Project (BBP)

50MW Large Scale Battery Energy Storage System

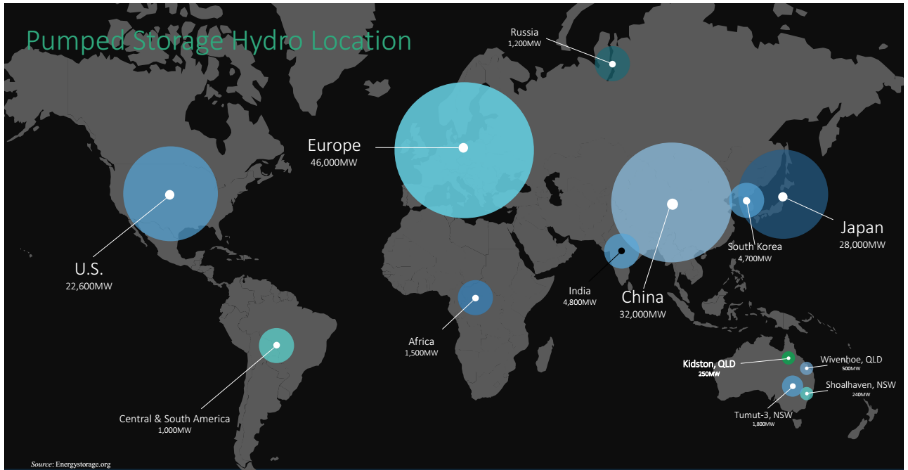
Jemalong Solar

50MW Jemalong Solar Project

Diversified clean energy generator

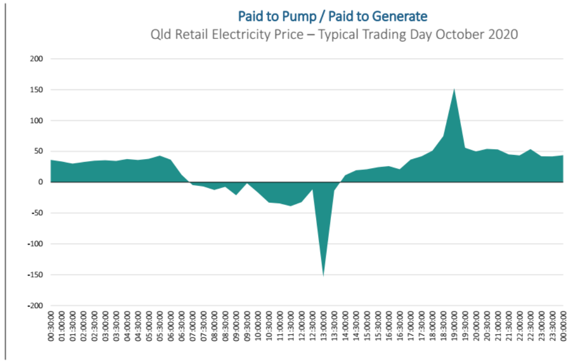
Project	Status	Counterparty	Revenue Model
Kidston Stage 1 50MW Solar Project	Production (since 2017)	Queensland Government	20-year Government Revenue Guarantee. Selling into National Energy Market
Jemalong Solar 50MW Solar Project	Energisation	AEMO	Merchant/Spot
K2-Hydro 250MW Pumped Hydro Project	Genex FID	EnergyAustralia	Long term rental over the pumped hydro assets
Bouldercombe Battery 50MW Large Scale Battery Energy Storage System	Development	To be confirmed	Contract/Merchant
K3-Wind 150MW Wind Project	Feasibility	To be confirmed	To be confirmed
K2-Solar Up to 270MW Solar Project	Feasibility	To be confirmed	To be confirmed

Pumped Storage Hydro Location

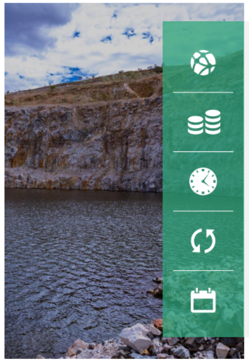


Evolving energy market – the need for storage

- Growth of intermittent wind & solar creating volatility in the market.
- Need for low-cost, large-scale storage to facilitate high penetration of renewables and maintain reliability requirements.
- 5-minute settlement in 2022 likely to increase price volatility.
- Pumped hydro can ramp up in under 30 seconds to dispatch into 5 min pricing (gas closer to 15 minutes from cold start).



Pumped Storage Hydro



Mature technology – in use for over 130 years, with > 200 projects worldwide.

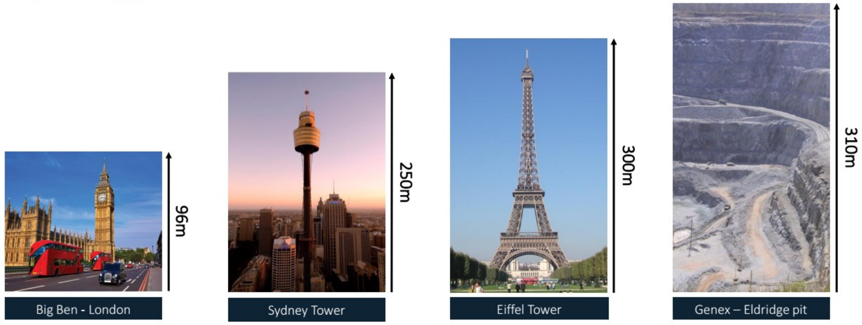
Lowest cost of energy storage available – 250MW Kidston Project with up to 8 hours of storage is ~15x more affordable than the cost of equivalent lithium-ion battery storage.

Peak power generator – able to dispatch into periods of high demand.

Can be integrated with renewables – perfect component to firm intermittent renewable generation.

80+ year project lifespan.

Hydro: Bigger IS better



Volume: enough water to fill an Olympic pool every 15 seconds

250MW Kidston Pumped Storage Hydro Project

Utilising the two existing mining voids to significantly reduce capital expenditure (a world first):
- Mining voids are 42ha & 54ha; and
- Substantial rehabilitation after mine closure in 2001.

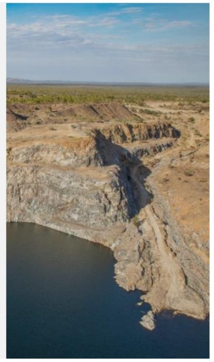
Strategic location given existing infrastructure.

Design optimized for up to 8 hours of peaking, dispatchable generation (2,000MWh).

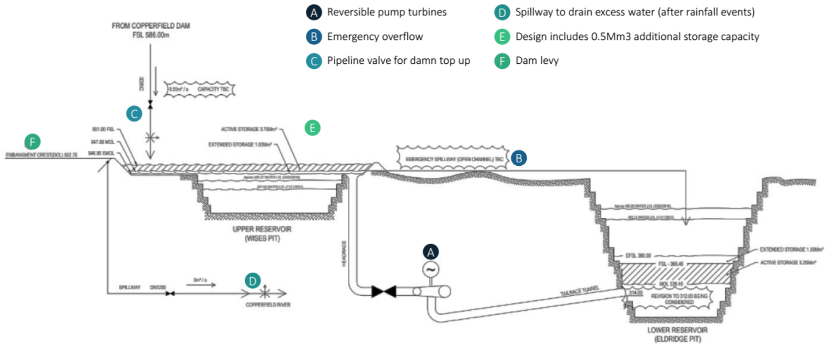
Water licence in place for external top-up if required.

Development of project and construction of power line will contribute to system strength and unlock additional wind and solar opportunities in the region.

Finalising arrangements with funding partners.

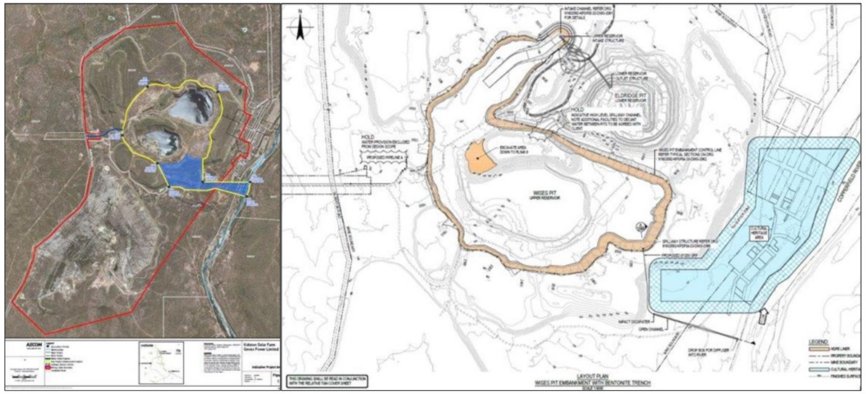


Legacy topography assists the project



* Not to scale

Minimal Environmental Footprint



Andritz Hydro Equipment

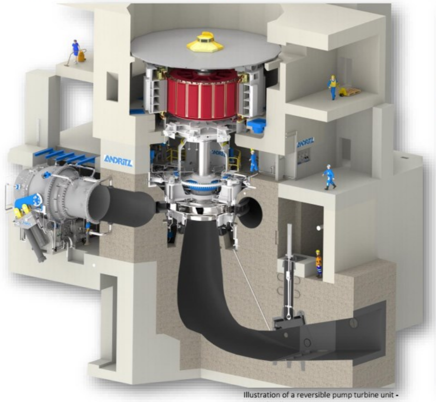
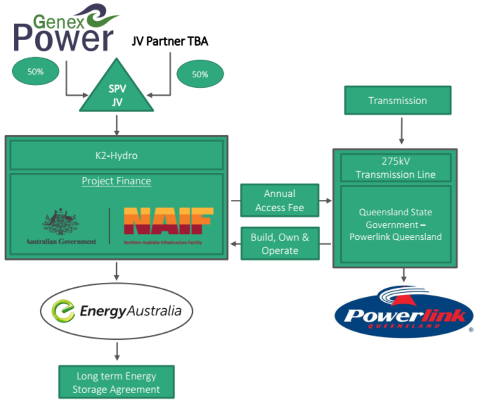


Illustration of a reversible pump turbine unit • Photo for illustrative purposes

Photo for illustrative purposes

K2-Hydro ownership and funding structure



K2-Hydro funding strategy made up of:

- EnergyAustralia Long term contracted revenue;
- NAIF Concessional funding for 100% of debt for the project;
- Equity funding at project level (discussions progressing); and
- J-POWER cornerstone shareholding in Genex.

* Up to 19.99%, conditional upon shareholder approval and hydro financial close

K2-Hydro – Status of Counterparties

EnergyAustralia	**Energy offtake** • Energy Storage Services Agreement signed with EnergyAustralia.
J-POWER	**Genex equity investor** • SSA signed for up to $25m equity investment in Genex Power.
John Holland / McConnell Dowell / Andritz	**EPC Contractor/supplier of pump turbines** • Binding EPC Contract ready to execute, Early Works Stage 1 completed, pricing and terms agreed.
NAIF	**Federal Government** *Sole lender providing up to $610 million of long-term, concessional debt.* • Board Investment Decision granted, to be updated for revised offtake arrangement.
ARENA	**Federal Government Grant Body** • Discussions being finalised.
Powerlink	**Queensland Government** *Construct and operate 275kV transmission line from Kidston to Mt Fox.* • Offer to Connect submitted, GPS approved, pricing revalidated.
Queensland Government	**Treasury/DNRME – co-funding of Transmission line** • Discussions well advanced, to be concluded as a priority.

Demonstrated track record of project delivery

Delivered Kidston 50MW solar project on time and budget.

- 540,000 solar panels installed, 160 workers on site & developed within 12 months.

Delivered Jemalong 50MW solar project on time and budget.

- 152,000 solar panels installed, 80 workers on site & developed within 12 months.
- No delay to project construction or commissioning schedule despite impact of COVID-19.

UGL, SMA, First Solar, NEXTracker, JinKO Solar, beon, blueshore

Kidston 50MW Solar Project

Jemalong 50MW Solar Project

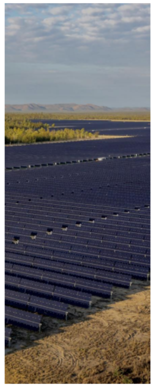
Stage 3: 150MW Kidston Wind Project

- Stage 3 of the Kidston Clean Energy Hub (a Globally unique integration of solar, wind and hydro) .
- Development funding agreement signed with J-POWER to earn 50% in the project through an initial A$1.5m funding investment[1].
- J-POWER have over 1GW of wind power in their portfolio (including projects under construction).
- The $1.5M investment will be used to expedite the development of the Project through monitoring, planning and other feasibility workstreams over the next 12-18 months.
- K3-Wind will leverage existing infrastructure (transmission line) and co-location advantages to K2-Hydro. The land portfolio has been secured.
- Combination of wind, solar and hydro completes the Kidston Clean Energy Hub.
- Good wind resource with two sites secured.

1. The Agreement is subsequent to, and independent of, the signing of the Share Subscription Agreement with J-POWER for investment of up to A$25M in Genex, executed in August 2020 (*refer ASX Announcement 3 August 2020*).

Genex – clean energy credentials

Clean Energy Production	Maximum Generation (Calendar Year)	Offsets CO_2 Production (Calendar Year)	Houses Powered (Calendar Year)
2020	**KS1:** 50MW – 145,000MWh	120,000t of CO_2	22,070
2021/22	**KS1:** 50MW – 145,000MWh **JSP**: 50MW – 128,700MWh **BBP**: 50MW - 27,375MWh	249,166t of CO_2	45,826
2024	**370MW** – 1,056,700MWh **250MW** – 730,000MWh **150MW** – 525,600MWh **50MW** – 27,375MWH	1,936,282t of CO_2	356,115



Notes to the table:
Assumes KS1 is generating at full capacity; Assumes JSP is generating at full capacity; Assumes K2-Solar is built & generating at full capacity of 270MW; Assumes average daily household consumes 18kwh/day
Assumes K2-Hydro dispatches once a day; K3-Wind based on a typical wind farm in the region with a capacity factor of 40%; Assumes K2-Hydro pumps water using green energy: Assumes battery dispatches once a day & charges using green energy

Creating a leading listed renewable energy and storage company

1 — Diverse renewable energy and storage portfolio

- 2 operating 50MW solar projects (KS1 & JSP).
- KS1 is underpinned by long term energy contracts providing secured revenue and cashflow stream.
- K2-Hydro project to provide significant growth.
- BBP diversifies Genex's renewable energy & storage profile.
- K3-Wind project provides longer term growth.

2 — Proven track record of project execution

- Developed, financed and built KS1 and JSP solar projects.
- Both projects delivered on time and budget.
- Successfully developed >$200m worth in projects.
- Installed total of 692,000 solar panels.
- Strong project management and construction expertise.

3 — Strong relationships across a diverse range of stakeholders

- Strong portfolio of stakeholders has been cultivated with a culture of project delivery.

ARENA | NAIF | Queensland Government | CS Power | EnergyAustralia | Powerlink | CEFC

4 — Significant upside from development of K2 Hydro project

- 250MW pumped storage hydro project.
- Debt funding in place through NAIF.
- Offtake secured with EnergyAustralia.
- Construction to commence Q1 CY2021.
- First energy dispatch scheduled for CY2024.

Contact

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Mob: 0414 785 009

Email: sk@genexpower.com.au

Board and Management

Dr. Ralph Craven (Chairman)
- Former Chairman of Stanwell Corporation
- Director of Senex and AusNet Services
- Former Chairman of Ergon Energy
- Former CEO of Transpower New Zealand

Simon Kidston (Executive Director)
- Founder of EndoCoal and Carabella
- Former banker with HSBC, Macquarie, Helmsec

Ben Guo (Finance Director)
- 13 years finance and accounting experience with PWC, E&Y, Helmsec and Carabella Resources

Michael Addison (Director)
- Founder of EndoCoal and Carabella
- Water Engineer with extensive finance experience

Teresa Dyson (Non-Executive Director)
- Director of Energy Queensland, Seven West Media & Energy Super, Power & Water Corporation
- Former Partner of Ashurst & Deloitte
- Member of FIRB and Takeovers Panel

Yongqing Yu (Non-Executive Director)
- Engineering background with extensive global hydro experience
- Vice Chairman of Zhefu

James Harding (Chief Executive Officer)
- 30 years experience in international project business
- Former head of Business Development in Abengoa Solar Power Australia & General Manager of Renewables with IPS Australia and MAN Ferrostaal

Arran McGhie (Chief Operations Officer)
- 20 years experience in senior project management roles for underground excavation and civil construction projects
- Management roles with Lend Lease, John Holland, CPB Contractors and Thiess

Justin Clyne (Company Secretary)
- 15 years experience in the legal sector
- 10 years experience as a corporate governance specialist
- Director and Secretary of a number of listed & unlisted public companies

Craig Francis (General Manager - Commercial Finance)
- Over 13 years investment banking and finance experience in Australia and the UK focusing on the energy and natural resources sectors

Wendy Moloney (Business Development Manager)
- Over 12 years experience in feasibility, acquisition, financing, delivery and operations of renewable energy projects in Australia and the UK

Harrison Holihan (Commercial Manager)
- Bachelor of Science (Psych) – University of Sydney
- Undergraduate Certificate – Oxford University
- Masters in Environmental Science – Harvard University (Active)

Disclaimer – February 2021

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Genex Power

Corporate Presentation | Renewable Energy on Tap | February 2021 | Genex Power (GNX) 25

Presentation 6: Lamtakong Jolabha Vadhana Hydro Power Plant, Thailand - Mr.Buntoon Nakasiri (EGAT's System Operator)

EGAT

LAMTAKONG JOLABHA VADHANA HYDRO POWER PLANT (LTK-H)

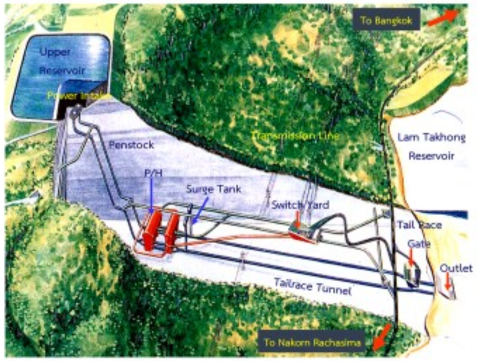
APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply

Online, 2-5 February 2021

Mr.Buntoon Nakasiri (EGAT's System Operator)

LAMTAKONG JOLABHA VADHANA HYDRO POWER PLANT (LTK-H)

- **Location**: Sikhio and Pak Chong district, Nakhon Ratchasima province
- **Capacity**: 1,000 MW [4 x 250 MW (pumped storage hydropower PSH)]
- **Turbine-Pump**: Reversible vertical shaft francis type (Fixed-speed pump)
- **Phase 1** : 2 x 250 MW COD July 2547
- **Phase 2** : 2 x 250 MW COD December 2562



Upper reservoir :

- Asphalt faced rockfill covered with HDPE
- Crest length : 2,170 meters
- Height : 50 meters
- Total storage : 10.3 cubic meters
- Effective storage : 9.9 cubic meters
- Storage level : 620-660 meter (MSL)
- Discharge duration at rated power : 8 hours
- Surface covers : 0.34 square kilometers

Penstock :

- Diameter : 2.4 - 6 meters
- Length : 651 meters

Tailrace :

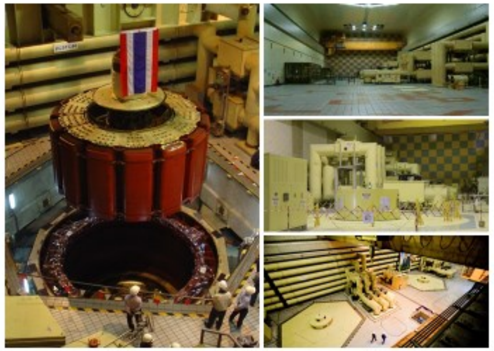
- Diameter : 4.4 - 6.8 meters
- Length : 1,430 meters

Power House :

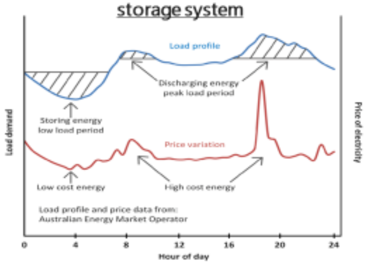
- Width : 23 meters
- Length : 175 meters
- Height : 47 meters
- 350 meter underground
- 4 Units of Generator / Motor

Generator / Motor :

- 3-Phase AC Synchronous
- Rated output : 282 MVA
- Voltage : 16.5 kV
- Generator/Motor : 250 MW / 260-270 MW
- Frequency : 50 Hz
- Revolving speed : 429 rpm (14 pole)
- PF (Generator) : 0.90 (lagging)
- PF (Motor) : 0.98 (leading)
- Transformer : 288 MVA (16.5/230 kV)
- From shut down to full load generation : 7 minutes
- From shut down to pumping : 15 minutes

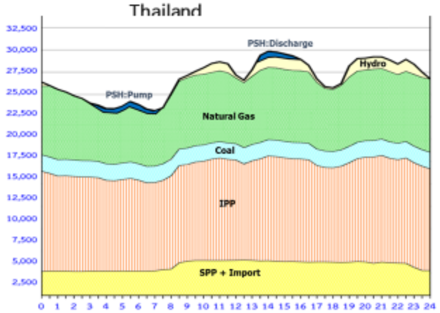


Idea for Energy shifting using energy storage system



Source: Katsanevakis, Markos & Stewart, Rodney & Lu, Junwei. (2016). Aggregated applications and benefits of energy storage systems with application-specific control methods: A review. Renewable and Sustainable Energy Reviews.

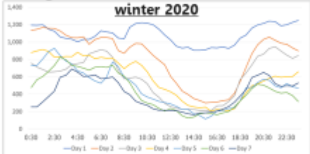
Utilization of PSH in Thailand



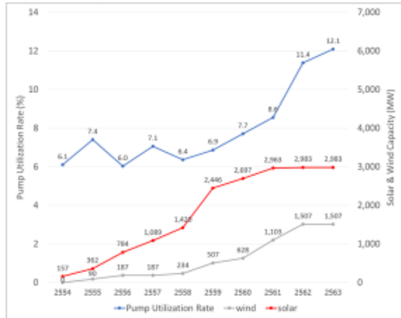
The effect of RE on the system that makes PSH more important

EGAT system generation on new year's day for the past 5 years

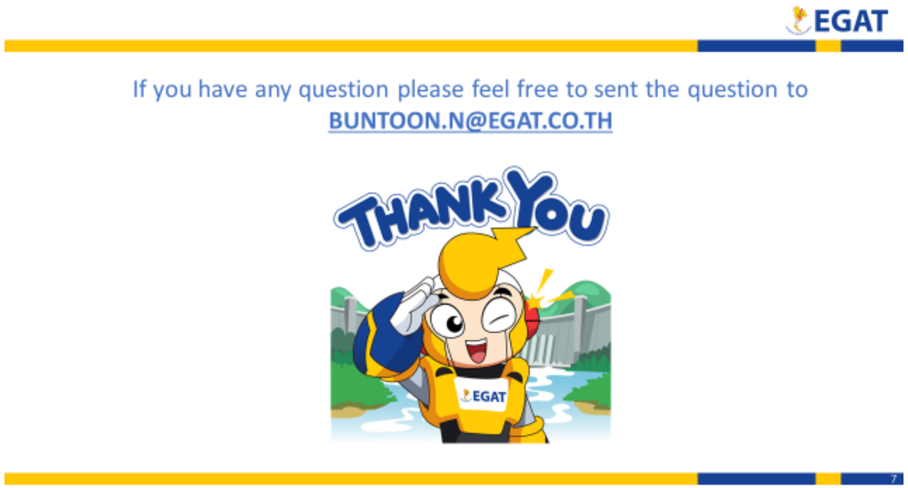
Wind generation characteristic in 1 week in winter 2020



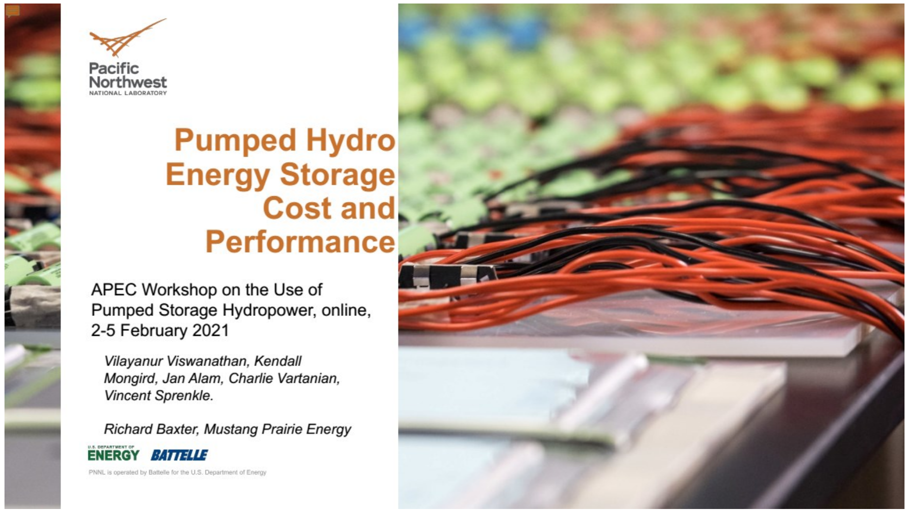
Pump Utilization Rate and Solar & Wind

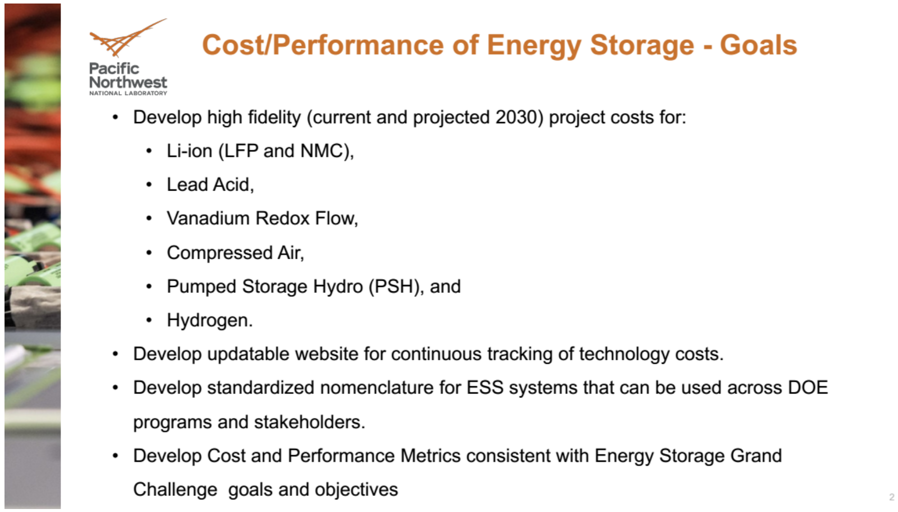


(Pump Utilization Rate = Pumping Hour / Pump Available Hour)



Presentation 7: Pumped Hydro Storage Cost and Performance - Vilayanur Viswanathan





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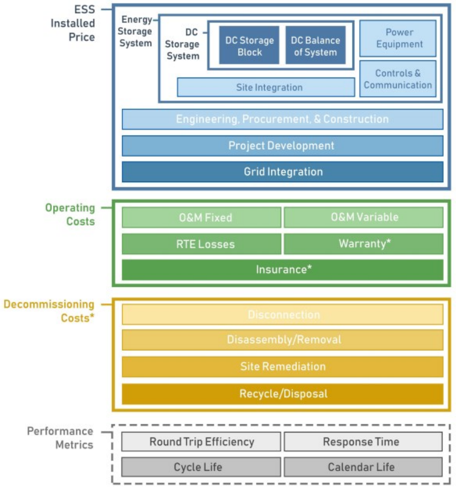
Energy Storage Subsystems & Performance Metrics



*Estimates for these components are not included at this time in techno

3

ESS Installed Cost Definitions

	Proposed ESGC Energy Storage System Price Category	Definition	Example: Li-ion	Example: PSH
ESS Installed Price	**DC Storage Block (DCSB)**	Price for the most basic DC storage element in system, expressed in $/kWh. e.g. for Li-ion, price would include battery module, rack, BMS, comparable to vehicle pack price.	Li - ion rack or pack	PSH Reservoir costs
	DC Storage Balance of System (DCSBOS)	Expressed in $/kWh and includes supporting components for storage block including container, cabling, switchgear, flow battery pumps, HVAC, etc.	Li-ion balance of system	
	DC Storage System (DCSS)	*DCB + DCSBOS*	*Li-ion DC Storage System*	
	Power Equipment	Bi-directional invertor, dc-dc converter, isolation protection, AC breakers, relays, communication interface, DC-DC converters, software, expressed in $/kW. This is PCS for batteries, powerhouse for PHS and powertrain for CAES	Power Conversion System (PCS)	Electromechanical and powerhouse construction.
	Controls & Communication	Energy management system for entire energy storage system responsible for ESS operation. (Typically fixed price independent of E/P ratio, but scalable wrt power) May include annual licensing fee for software	Controls/EMS	
	ESS	*Combination of all of above. This is the price the systems integrator charges the end user*	*BESS*	
	Engineering Procurement and Construction (EPC)	Includes non-recurring engineering (NRE) costs, construction equipment, and shipping, siting and installation & commissioning the energy storage system. Reported in $/kWh with weighting based on E/P ratio.		EPC, PD, GI mostly contained in above categories. This captures contingency from unanticipated risks
	Project Development	Cost associated with permitting, Power Purchase Agreement, interconnection agreement & financing.	Project development.	
	Grid Integration	Cost to ESS owner associated with connecting the ESS system to the grid, including price for transformer, meters, isolation breakers - single disconnect breaker vs. breaker bay for large system		

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Basic PSH Cost Breakdown Methodology

PSH does not generate DC power, most basic PHS element includes capital cost for upper, lower reservoirs, powerhouse, etc. needed for operational storage system.

PSH Costs = Reservoir costs + Powerhouse + electromechanical costs + unanticipated costs (contingency fee).

No cost are associated with building transmission lines if PSH site located away from existing transmission lines

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General Methodology

- Prices derived from multiple sources
  - Reference Literature
  - Commercial Database
  - Stakeholder Interviews
- Scaling information obtained from literature sources
- Scaled price information from vendors to fit specific Energy to Power ratio
  - Durations considered: Li-ion (2, 4, 6, 8, 10 hours), Pb-acid (4,10 hours), Flow Batteries (4,10 hours), PSH (4,10 hrs), Compressed Air (10 hours), Hydrogen (10 hours)*
- Additional Categories (e.g Warranty, Insurance, Decommissioning Costs) are added to Matrix for completeness but lack justifiable numbers at this point.

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Pumped Storage Hydro Price Reference Data

Total System Cost

• Gordon Butte 400 MW, 8.5h (*PNNL number is $2234/kW*)	$2400/kW	[1]
• Average of multiple plants in Germany (2013-2019 planned completion)	$1792/kW	[2]
• Average of 4 sites in Portugal and Spain	$2667/kW	[3]
• Interview with PSH Stakeholders - with contingency fee	$2500 to 3500/kW	
• Interview with PSH Stakeholders - without contingency fee	$1875-2625/kW	

[1] https://www.utilitydive.com/news/1b-montana-pumped-hydro-project-secures-funding/558833/
[2] B. Steffen, Prospects for pumped-hydro storage in Germany, Energy Policy 45 (2012) 420-429
[3] J.P. Deane et al, "Techno-economic review of existing and new pumped hydro energy storage plant", Renewable and Sustainable Energy Reviews 14 (2010) 1293–1302

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Various category Costs

Powerhouse cost

- $943/kW based on cost to build powerhouse in site in Switzerland with existing reservoirs [3]
- $742/kW - Interview with PSH Stakeholders - without contingency fee

Electromechanical cost

- $974/kW based on expansion into existing complexes in Switzerland [3]
- $622/kW Interview with PSH Stakeholders - without contingency fee

Reservoir cost

- $77/kWh Interview with PSH Stakeholders - without contingency fee

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PSH Cost Breakdown – Stakeholders Interview 2020

- Obtained Total $/kW and electromechanical $/kWh range from PSH stakeholders
  - $2500 (8-10h) to 3500/kW (16-20h) – includes contingency fee
- Contingency fee was 25% of total cost
- Costs for various components without contingency fee:
  - Electromechanical and C&I costs estimated for each duration - $467/kW
  - Reservoir C&I costs backed out - $77/kWh
  - Calculated $/kW for powerhouse C&I - $742/kW
  - Applied scaling for cost as f(MW) with MW spanning > 2 orders of magnitude (*International Journal on Hydropower and Dams, December 2018, EPRI 1023140 2011*)
    - ✓ Used the lower scaling factor – *EPRI 2011*
  - 33% increase due to contingency lines up nicely with our approach of adding systems integrator, EPC and Project Development costs

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O&M Costs – stakeholder interview 2020

- Fixed O&M
  - Assign labor for 1000 MW plant as follows: (HDR)
  - 32 persons, $100K per person – total labor $3.2M
  - Parts/consumables – 3/7 times above labor cost or $2.4/kW-year
    - ✓ fixed for all plant sizes
  - Assume for each 10X lower MW capacity, labor cost reduces only by factor of 2
    Labor $/kW-year increases as MW capacity decreases
  - Every 5 years do outage and some repairs– 1% of capital cost
  - Every 10 years do deep repair - 5% of capital cost
  - Every 20 years do major overhaul, replace rotor, slip seals, rewire stator, at 15% of capital cost
    - ✓ Total is $9/kW-year for fixed refurbishments
  - At 1000 MW, O&M costs align well with [4]
  - Across the 10 to 1000 MW range, O&M costs align with [5]

[4] IRENA June 2012, Volume 1: Power Sector, Issue 3/5
[5] P.W. O'Connor et al, "Hydropower Baseline Cost Modeling, Version 2", ORNL/TM-2015/471 September 2015

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Results PSH, 4-h system

Power (MW)	$/kWh	10	100	1000
Duration (h)		4	4	4
MWh		40	400	4000
C&I cost for reservoirs, $/kWh	77			
C&I cost for powerhouse, $/kW	742			
$/kW electro-mechanical	467			
Apply MW scaling $/kW		1440	1209	1015
Apply MWh scaling, $/kWh		97	81	68
Total $/kW		1828	1534	1288
Total $/kWh		457	384	322
With contingency $/kW		2437	2046	1717
O&M fixed labor, $/kW-year		78.7	15.7	3.1
O&M fixed parts, $/kW-year		5.6	5.6	5.6
O&Mfixed refurbishment		9.0	9.0	9.0
Total O&M Fixed		93.4	30.4	17.8
% of cap cost		5.1%	2.0%	1.4%

Results PSH, 10-h system

Power (MW)		10	100	1000
Duration (h)		10	10	10
MWh		100	1000	10000
C&I cost for reservoirs, $/kWh	77			
C&I cost for powerhouse, $/kW	742			
$/kW electro-mechanical	467			
Apply MW scaling $/kW		1440	1209	1015
Apply MWh scaling, $/kWh		90	76	64
Total $/kW		2344	1967	1651
Total $/kWh		234	197	165
With contingency $/kW		3125	2623	2202
O&M fixed labor, $/kW-year		78.7	15.7	3.1
O&M fixed parts, $/kW-year		5.6	5.6	5.6
O&Mfixed refurbishment		9.0	9.0	9.0
Total O&M Fixed		93.4	30.4	17.8
% of cap cost		4.0%	1.5%	1.1%

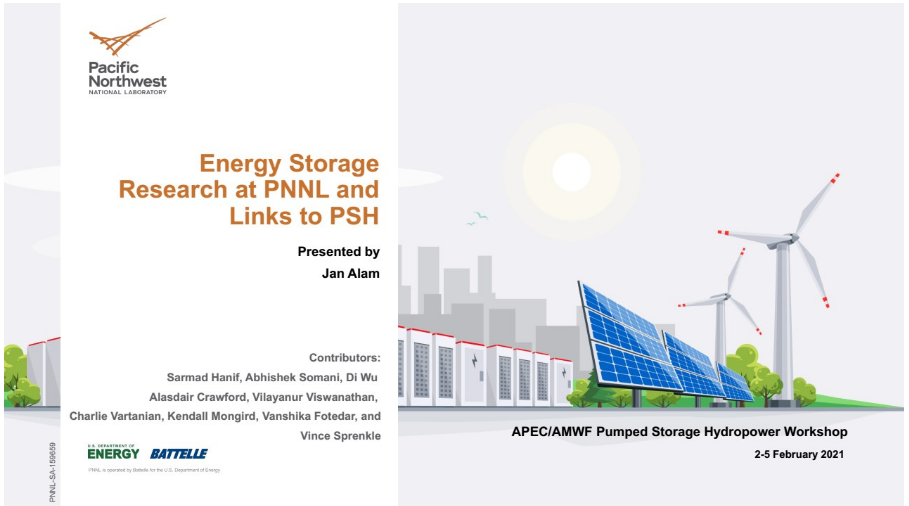
PSH Cost 10, 100, 1000 MW @ 4,10h

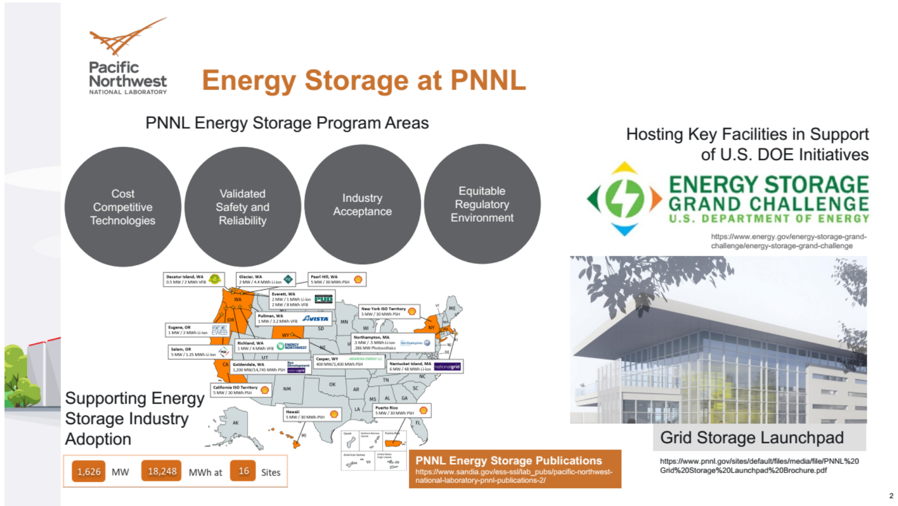
	Parameter	Units	10 MW		100 MW		100 MW	
			4h	10h	4h	10h	4h	10h
	Capital Cost	$/kW	$1,828	$2,344	$1,534	$1771	$1,288	$1,651
	Power Conversion System	$/kW	Included in Capital Cost		Included in Capital Cost		Included in Capital Cost	
	Total ESS Installed Cost	**$/kW**	**$1,828**	**$2,344**	**$1,534**	**$1,967**	**$1,288**	**$1,651**
	Total ESS Installed Cost	**$/kWh**	$457	$234	$384	$177	$322	$165
Operating Costs	Operations & Maintenance - Fixed	$/kW-yr	93.4		30.4		17.8	
	Operations & Maintenance - Variable	$/kWh	0.00051		0.00051		0.00051	
	System RTE Losses	$/kWh	0.008		0.008		0.008	
Performance Metrics	Round Trip Efficiency	%	80%		80%		80%	
	Cycles at 80% Depth of Discharge	#	15,000		15,000		15,000	
	Calendar Life	yrs	>25		>25		>25	

ESGC Website and link to report

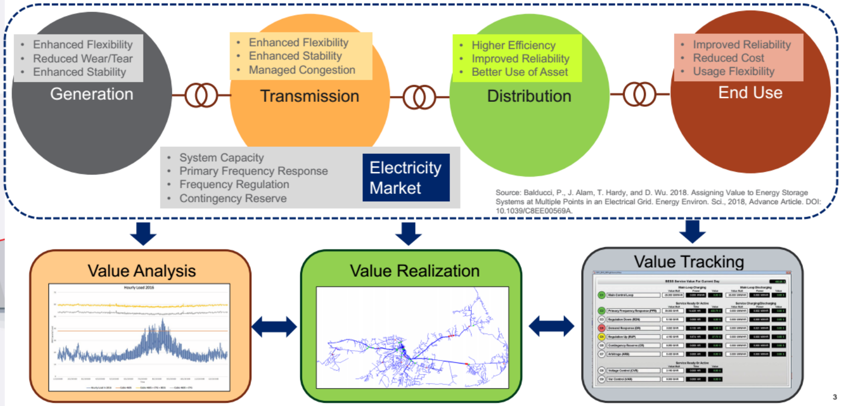
- https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf
- https://www.pnnl.gov/ESGC-cost-performance
- https://www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge?utm_medium=email&utm_source=govdelivery

Presentation 8: Energy storage research at PNNL and links to PSH - Jan Alam





Values and the Value Chain



Source: Balducci, P., J. Alam, T. Hardy, and D. Wu. 2018. Assigning Value to Energy Storage Systems at Multiple Points in an Electrical Grid. Energy Environ. Sci., 2018, Advance Article. DOI: 10.1039/C8EE00569A.

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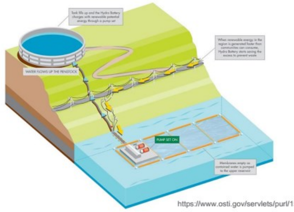
Illustrative PSH Evaluation Work at PNNL



https://www.osti.gov/servlets/purl/1526319

Goldendale Pumped Storage Hydro Project

- 1.2 GW, 12 Hour or more
- Clean energy resource capacity as thermal units retire
- Store surplus renewable
- Support the regional transmission system

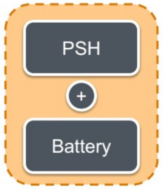
https://www.ryedevelopment.com/projects/goldendale-washington/

Shell Energy North America Hydro Battery System

- 5 MW, 6 Hour
- Benefits evaluated over multiple regions in the US for various transmission level services
  - Frequency response
  - Regulation
  - Reserve
  - System capacity

More Flexibility with PSH + Battery Hybrids?

- Evolving electricity grid
- Increasing renewable penetration
- Higher, faster balancing requirement
- Higher wear and tear
- Increased asset management cost



Hybrid Operation

PNNL is collaborating with multiple electric utilities to understand the potential benefits of hybridizing conventional generating units with battery energy storage.

Eugene Water and Electric Board Carmen Smith Hydro Generating Facility

http://www.eweb.org/about-us/news/federal-regulators-grant-new-license-for-carmen-smith-hydro-project

Acknowledgement

U.S. DEPARTMENT OF ENERGY

Dr. Imre Gyuk, Office of Electricity, U.S. Department of Energy

Questions and Comments

Jan Alam, Jan.Alam@pnnl.gov | **Vince Sprenkle,** Vincent.Sprenkle@pnnl.gov

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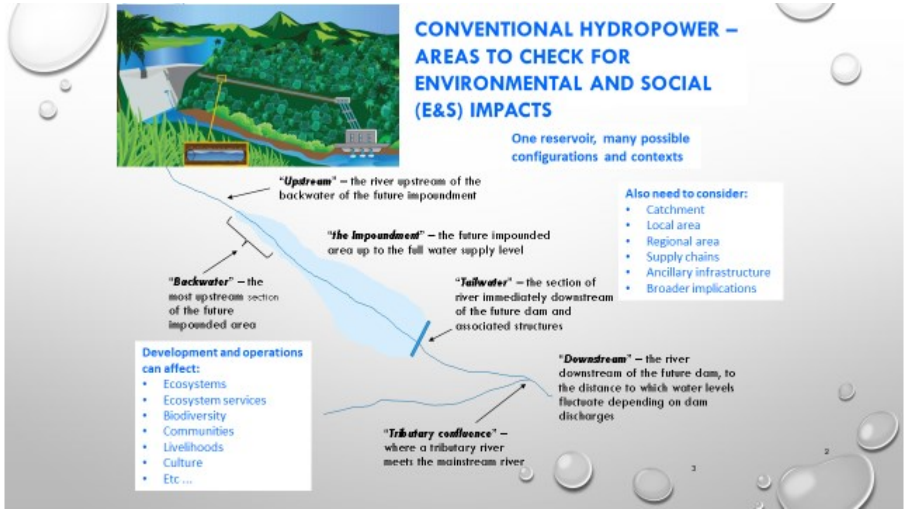
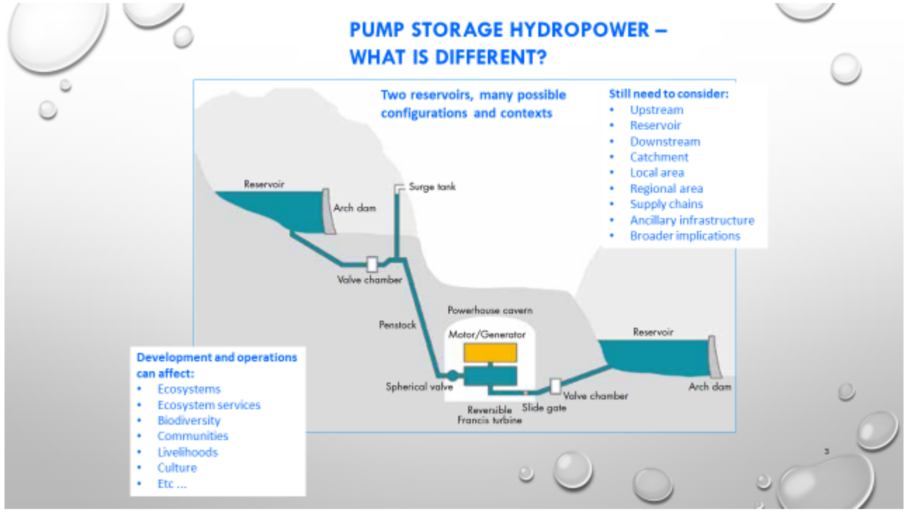
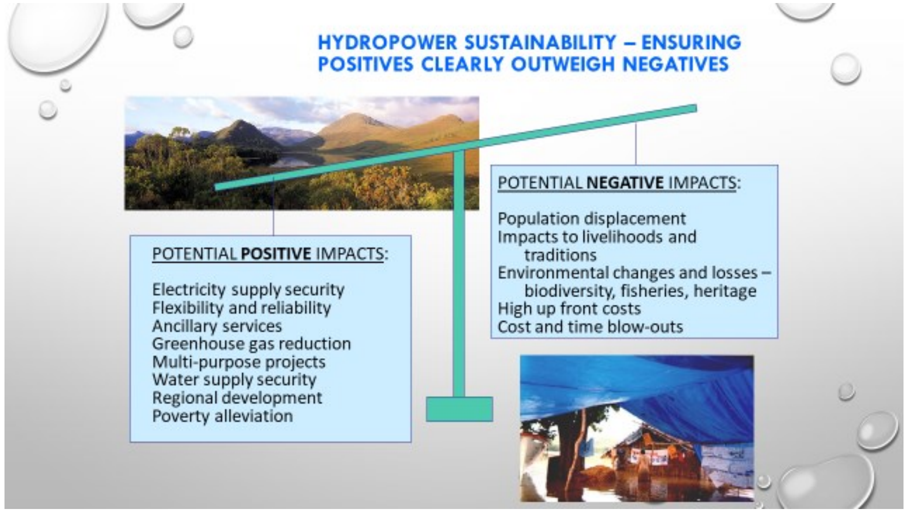
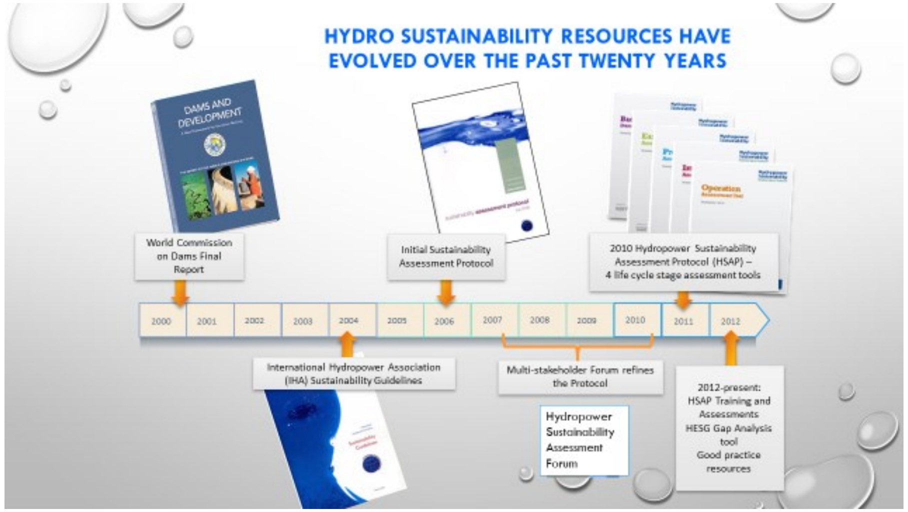
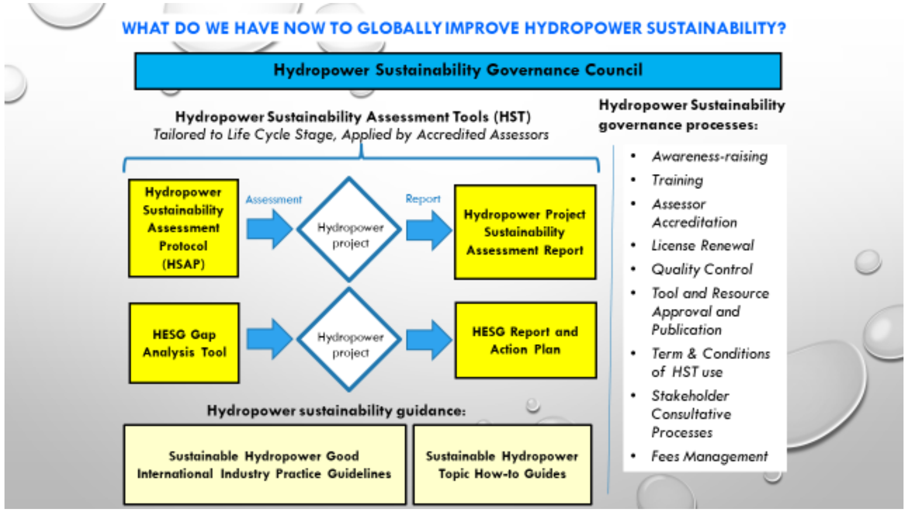
Presentation 9: Role of hydropower sustainability tools for pump storage hydropower - Helen Locher

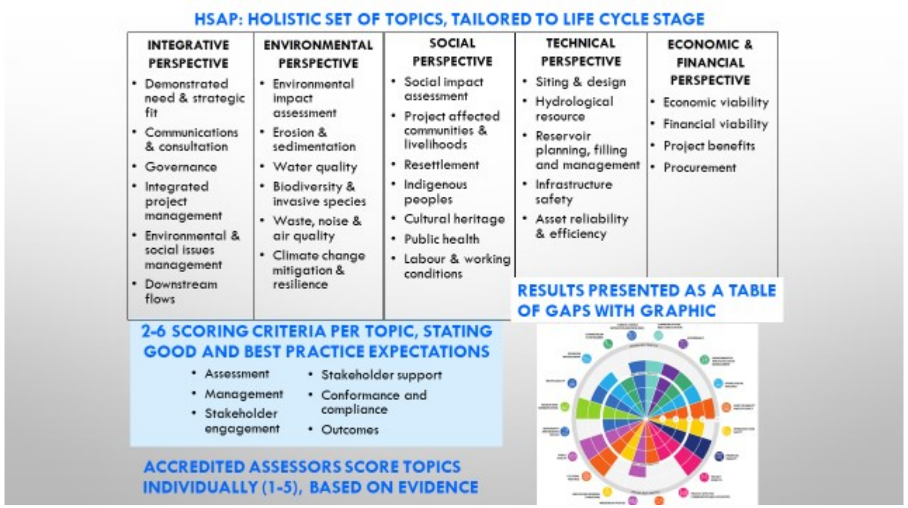






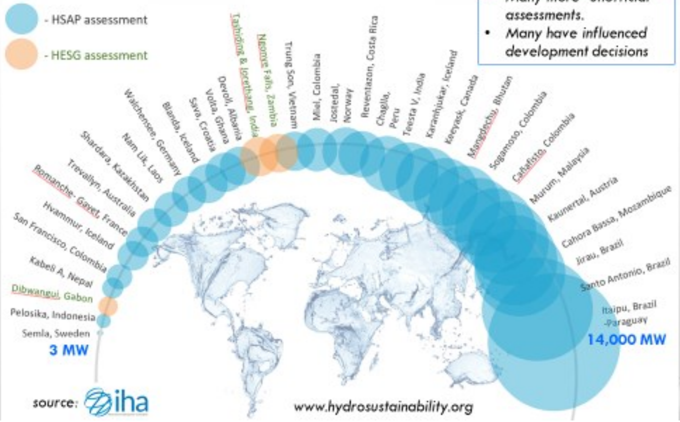

HYDRO SUSTAINABILITY RESOURCES HAVE EVOLVED OVER THE PAST TWENTY YEARS
DAMS AND DEVELOPMENT
World Commission on Dams Final Report
Initial Sustainability Assessment Protocol
2010 Hydropower Sustainability Assessment Protocol (HSAP) – 4 life cycle stage assessment tools
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
International Hydropower Association (IHA) Sustainability Guidelines
Multi-stakeholder Forum refines the Protocol
Hydropower Sustainability Assessment Forum
2012-present: HSAP Training and Assessments HESG Gap Analysis tool Good practice resources


WHAT DO WE HAVE NOW TO GLOBALLY IMPROVE HYDROPOWER SUSTAINABILITY?
Hydropower Sustainability Governance Council
Hydropower Sustainability Assessment Tools (HST)
Tailored to Life Cycle Stage, Applied by Accredited Assessors
Hydropower Sustainability Assessment Protocol (HSAP)
Assessment
Hydropower project
Report
Hydropower Project Sustainability Assessment Report
HESG Gap Analysis Tool
Hydropower project
HESG Report and Action Plan
Hydropower sustainability guidance:
Sustainable Hydropower Good International Industry Practice Guidelines
Sustainable Hydropower Topic How-to Guides
Hydropower Sustainability governance processes:
• Awareness-raising
• Training
• Assessor Accreditation
• License Renewal
• Quality Control
• Tool and Resource Approval and Publication
• Term & Conditions of HST use
• Stakeholder Consultative Processes
• Fees Management


HSAP: HOLISTIC SET OF TOPICS, TAILORED TO LIFE CYCLE STAGE
INTEGRATIVE PERSPECTIVE
• Demonstrated need & strategic fit
• Communications & consultation
• Governance
• Integrated project management
• Environmental & social issues management
• Downstream flows
ENVIRONMENTAL PERSPECTIVE
• Environmental impact assessment
• Erosion & sedimentation
• Water quality
• Biodiversity & invasive species
• Waste, noise & air quality
• Climate change mitigation & resilience
SOCIAL PERSPECTIVE
• Social impact assessment
• Project affected communities & livelihoods
• Resettlement
• Indigenous peoples
• Cultural heritage
• Public health
• Labour & working conditions
TECHNICAL PERSPECTIVE
• Siting & design
• Hydrological resource
• Reservoir planning, filling and management
• Infrastructure safety
• Asset reliability & efficiency
ECONOMIC & FINANCIAL PERSPECTIVE
• Economic viability
• Financial viability
• Project benefits
• Procurement
RESULTS PRESENTED AS A TABLE OF GAPS WITH GRAPHIC
2-6 SCORING CRITERIA PER TOPIC, STATING GOOD AND BEST PRACTICE EXPECTATIONS
• Assessment
• Management
• Stakeholder engagement
• Stakeholder support
• Conformance and compliance
• Outcomes
ACCREDITED ASSESSORS SCORE TOPICS INDIVIDUALLY (1-5), BASED ON EVIDENCE


HESG: 12 TOPICS ALIGNING WITH WORLD BANK GROUP STANDARDS, TAILORED TO LIFE CYCLE STAGE
RESETTLEMENT (NOT RELEVANT)
BIODIVERSITY AND INVASIVE SPECIES
INDIGENOUS PEOPLES (NOT RELEVANT)
CULTURAL HERITAGE (NOT RELEVANT)
COMMUNITY IMPACTS AND INFRASTRUCTURE SAFETY
GOVERNANCE AND PROCUREMENT
WATER QUALITY AND SEDIMENTS
COMMUNICATIONS AND CONSULTATION
LABOUR AND WORKING CONDITIONS
HYDROLOGICAL RESOURCE
ENVIRONMENTAL AND SOCIAL ASSESSMENT AND MANAGEMENT
CLIMATE CHANGE MITIGATION AND RESILIENCE
2-6 SCORING CRITERIA PER TOPIC, STATING GOOD PRACTICE
• Assessment
• Management
• Stakeholder engagement
• Stakeholder support
• Conformance and compliance
• Outcomes
ACCREDITED ASSESSORS IDENTIFY GAPS BASED ON EVIDENCE
RESULTS PRESENTED AS TABLE OF GAPS, A GRAPHIC AND AN ACTION PLAN

DOCUMENTED GLOBAL UPTAKE OF HYDROPOWER SUSTAINABILITY TOOLS



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CONFIGURATION OF A PUMP STORAGE HYDRO PROJECT MAY RESULT IN RELATIVELY LESS E&S IMPACT

PSH configurations could include, e.g.:

- Open loop system vs. closed loop system
- Greenfield project (a fully new development)
- Extending existing hydro (e.g. adding an upper reservoir)
- Re-operating existing hydro (e.g. reconfiguring 2 existing storages)
- Re-operating disused water storages (e.g. old mine pits)
- Integrating variable renewable hydro (e.g. floating solar)
- Seawater for the lower reservoir
- Must consider supporting infrastructure (transmission lines, roads, construction areas)

10

MANY FACTORS BEYOND PROJECT SCALE, TYPE AND CONFIGURATION CAN INFLUENCE HYDROPOWER SUSTAINABILITY

Project Characteristics

- Age / life cycle stage
- Mega / large / medium / small/ mini / micro
- Reservoir / run-of-river / pump hydro
- Single HPP / cascade / integrated hydro system
- Inter- or intra-basin diversion scheme
- Single purpose / multi-purpose
- Location / geography / important values
- Social, environmental, stakeholder issues
- Operating patterns
- Mitigation measures

Market Context

- Single off-taker
- National or regional grid
- Trading market
- Market services

Company Characteristics

- Local / multi-national
- Large / small-medium
- Public / private / PPP
- Hydropower experience
- Corporate policies / capacities
- Stakeholder relations
- Financial position
- Commitment

Development Context

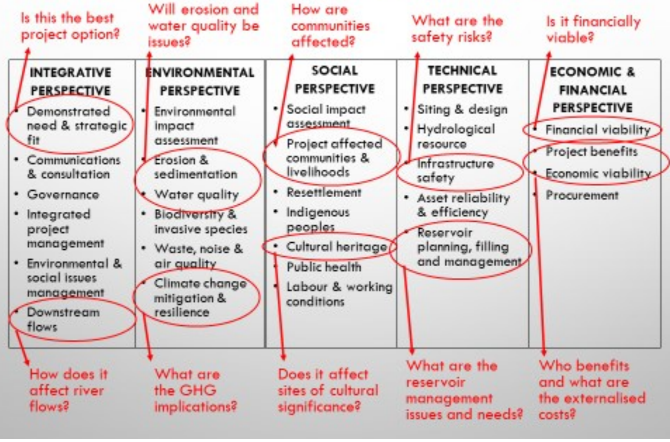
- Developed / developing
- Demonstrated need
- Options available
- Regulatory requirements
- Institutional capacities
- Transparency index
- Corruption index

Basin Context

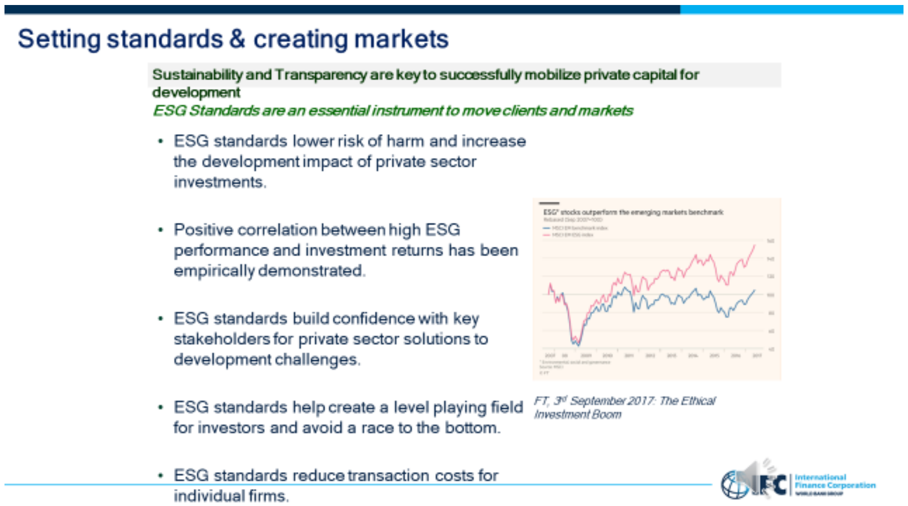
- Number / relationship of projects
- Complexity of ownership
- Degree of coordination of operations and mitigation measures

11

THE HYDROPOWER SUSTAINABILITY TOOLS ASK THE RIGHT QUESTIONS REGARDLESS OF CONFIGURATION, SCALE, SETTING, ETC.



Presentation 10: Integrated management through landscape-level approaches - Kate Lazarus



Our Performance Standards help clients successfully manage risks in a fast-changing world (Level 1)

Client Application:

- All clients apply PS1 and PS2, plus the other PSs relevant to their business operations.
- IFC does not require clients to meet PS at commitment but to achieve them over a reasonable period of time.

Why a PS 1?

Applies to 100% of our investment projects

A systematic approach to managing environmental and social performance…

… is an investment that enables clients to identify and manage E&S risks that can affect the viability of their business

PS1: Assessment and Management of Environmental and Social Risks and Impacts

OBJECTIVES

Identify project E&S risks and impacts

Adopt mitigation hierarchy

- Anticipate, avoid
- Minimize
- Compensate or offset

Improve performance through an Environmental and Social Management System (ESMS)

Engagement with Affected Communities, other stakeholders

- Throughout project cycle
- Includes communications, grievance mechanisms

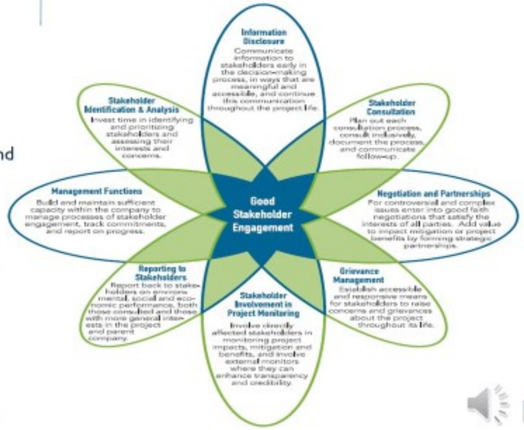
Establishing the appropriate management system

- Policy
- Identification of risks and impacts
- Management programs
- Organizational capacity and competency
- Emergency preparedness and response
- Stakeholder engagement, transparency, and grievance redress
- Monitoring and review

Stakeholder Engagement

Affected Communities:

- Informed Consultation and Participation (ICP)
- Broad Community Support (BCS)



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PS1: Assessment and Management of Environmental and Social Risks and Impacts

How does it apply?

- **Understand the project:**
  - Construction (e.g. access, power, workforce, waste)
  - Operation (e.g. reservoir, run-of-river, base-load, peak generation)
- **Identify project E&S risks and impacts:**
  ESIA:
  - Good environmental and social baseline,
  - Impact assessment - site specific & cumulative,
  - Management strategy: apply the mitigation hierarchy: avoid, mitigate or offset.

Engagement with Affected Communities and other stakeholders:
- Transparent, meaningful and good-faith communication and engagement throughout project cycle
- Grievance mechanisms

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Level 2: EHS guidelines

General and sector specific

Provides acceptable and achievable, performance levels and measures

For common OHS risk including:

- Construction
- Operation
- Interaction with communities

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Level 3: Good practice notes

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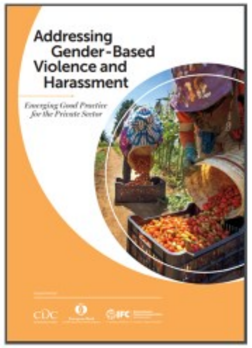
GPN: Gender based violence and harassment



- *Leadership and company culture* — Section 5.1
- *Policies and codes of conduct* — Section 5.2
- *Grievance mechanisms and investigation procedures* — Section 5.3
- *Recruitment and performance assessment* — Section 5.4
- *Training and awareness raising* — Section 5.5
- *Working with contractors and suppliers* — Section 5.6
- *Physical design* — Section 5.7

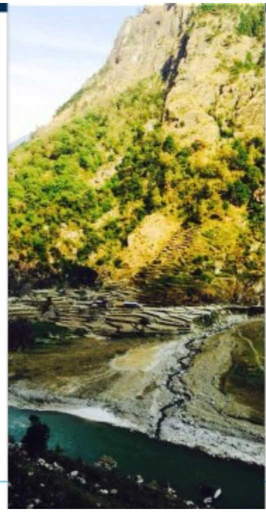
Level 4: Tools for screening, setting of systems

Upstream: Landscape Advisory

- A Landscape Advisory initiative is any on-the-ground E&S intervention that addresses risks that are beyond the ability of any one company to address on its own.
- Such an initiative creates an enabling environment as early as possible in the project cycle to increase private sector investment in the real sector by unlocking complex E&S challenges.

De-risk E&S issues when investment project(s) are already in pipeline

Engage to create a bankable pipeline of projects in a particular sector, country-wide



Landscape: Focusing on our watersheds to balance development & conservation

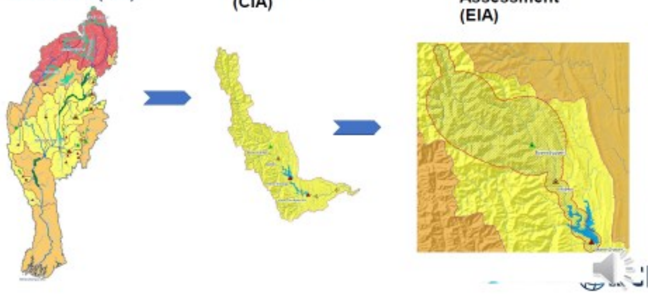
- When operating in such complex environments ESG challenges are often beyond the ability of one company to solve alone...
- Sectors that depend on the presence of natural resources tend to be geographically concentrated (e.g., hydropower, wind and solar power, agribusiness, OGM), collectively affecting the same E&S receptors (e.g., communities, biodiversity, human rights, water, security)
- The standard approach of assessing risks and impacts through a project-only lens is inherently limited when companies are operating in close proximity - companies will not readily share data or collaborate on assessments, leading to a duplication of efforts and an inability to monitor as data collection methods are often variable
- Addressing key E&S issues at the ESIA stage, is often too late for effective management, especially when operating in sensitive environments
- There is a barrier to investment when no single entity has the ability, leverage and technical know-how to convene multiple stakeholders to collectively address risks and impacts and define solutions
- Upstream engagement is required to avoid impacts and the need for high-risk, costly mitigations (e.g. offsets) and reduce the chances of unexpected delays arising from stakeholder concerns

Integrated Planning Levels

Basin
Strategic Environmental Assessment (SEA)

Sub-basin
Cumulative Impact Assessment (CIA)

Project
Environmental Impact Assessment (EIA)



Environmental "flashpoints"

Biodiversity Impacts
- Terrestrial & Aquatic Fauna
- Forestry
- Critical habitats

Ecological Flow
- Fisheries & other aquatic fauna
- Livelihoods/Cultural heritage

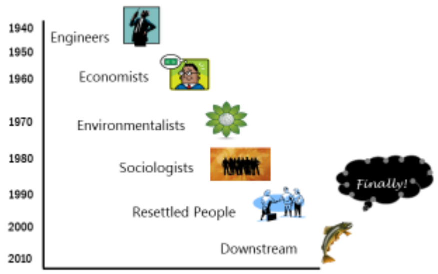
Cumulative Impacts
- Upstream
- Downstream
- Basin-wide

Climate Change Impacts

Sediment

- **Good baseline information**

Evolution of Thinking



Social "flashpoints"

Land acquisition
- Physical displacement
- Livelihood risk
- Cultural heritage

Labor Influx
- Risks to public health and safety
- Cost of goods & services/Inflation
- Threats to community resources

Employment

Stakeholders

Engagement

IPs

Gender (GBV)

- CONSTRUCTION
  - Disclosure and Consultation
  - Documentation (who, what, where)
  - Community liaison
  - Local procurement of goods & services
  - Grievance redressal at the project level
  - Early demonstration of tangible benefits
  - Secure labor camps
  - Traffic management
- OPERATION
  - Community liaison
  - Benefit sharing
  - Development, not philanthropy

Cumulative Impact Assessment: Hydropower Development in the Trishuli River Basin, Nepal

Challenges | **Opportunity**

- 216 MW UT-1 HPP in Nepal; complicated E&S landscape, limited capacity of government, stakeholder engagement, IPs; project on mainstem of Trishuli R.
- Lack of knowledge of basin wide impacts; lack of data; consistent survey methods
- Lack of understanding of Local shares requirements & IPs
- Lack of attention to gender
- Project-by-project approach.

Integrated Solutions

- Brought together all developers in TRB through Forum & exchanges at technical level between Nepal and Pakistan - ***convener.***
- Partnered with GoN & ICIMOD to improve EIA guidance; conducted Local Shares study; comprehensive basin-wide CIA; Environmental flows assessment, river connectivity transects, pioneered eDNA to monitor aquatic species, 1st FPIC, stakeholder, gender, etc. - ***technical lead.***
- **End-result**: Improved understanding through basin-wide studies/knowledge development; a multi-stakeholder platform to manage cumulative impacts, Locals shares policy guidance note to GoN and practitioners on Nepal's experience with offering shares in hydropower companies to PAPs. Business case for gender diversity in Nepal's Hydropower Sector launched.

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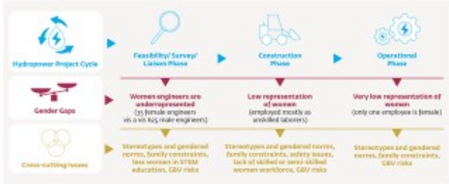
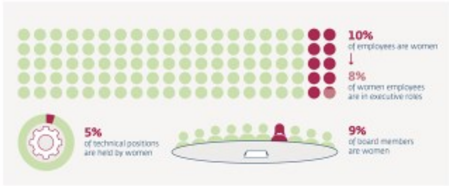
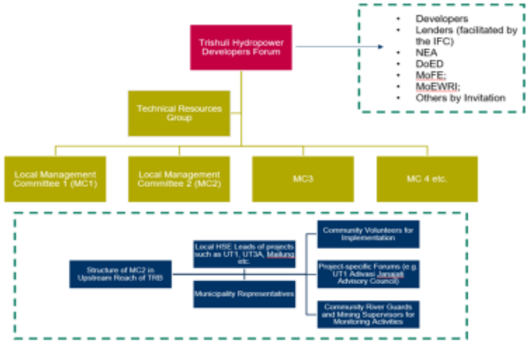
Gender gaps and cross-cutting issues in the hydropower project cycle





Institutional Arrangements



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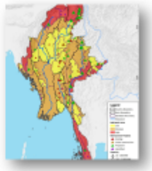
Hydropower Sector: Myanmar Strategic Environmental Assessment (SEA)

Opportunity

- Opening power sector key part of WBG strategy in Myanmar
- The objectives:
  - SEA provides an informed pathway for each major basin that takes a balanced approach, aiming to replace piecemeal project-by-project planning;
  - Designed to strike the balance between maintaining basin health and power development and facilitated market development;
  - Provides input to optimization studies, informs E&S requirements in tender documents.



Upstream Solution

- We brought together the developers through creation the Myanmar Hydropower Developers' Association, NGOs/CSOs and government authorities; created Advisory Group (58 engagements) - ***convener***
- Developed a replicable methodology for hydropower: conducted 7 baseline E&S thematic studies, evaluated E&S+ conflict conditions & trends; hydropower BAU sustainability analysis and prepared a sustainable development framework - ***technical lead***
- Achieved government agreement on the basin zoning/risk register - ***negotiator***
- **End-result**: The first comprehensive study to assess & plan complex system-level natural resource and development issues; tool for decision-making by government & private sector; conducted first CIA; guidance for IFC to select projects in lower risk basins and provide vital upfront information -***paving the way for de-risking investments***

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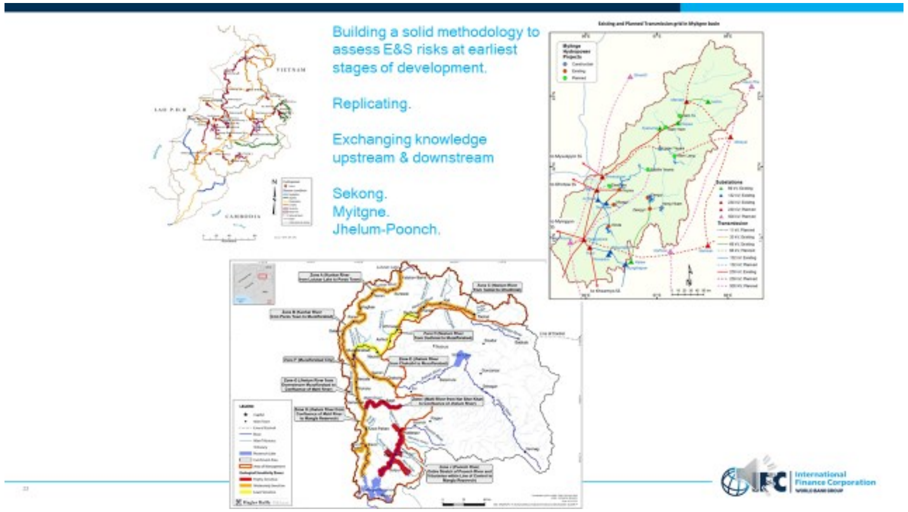
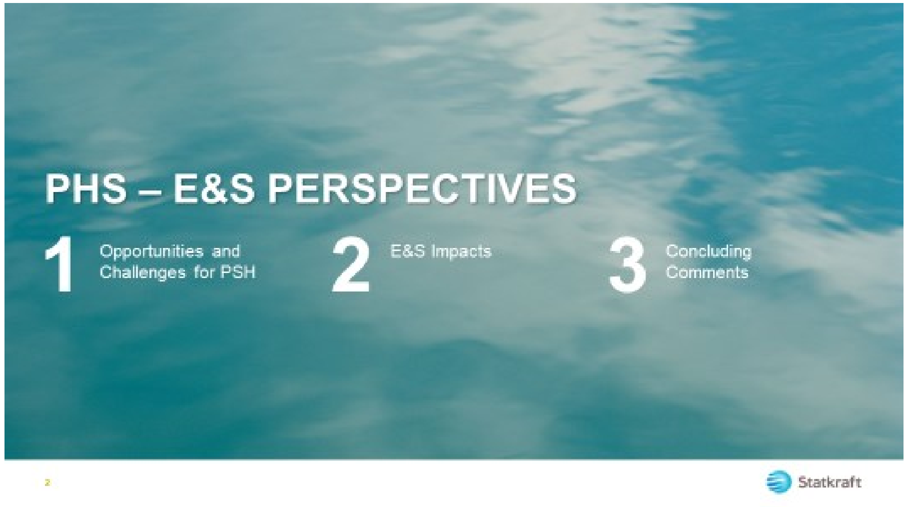
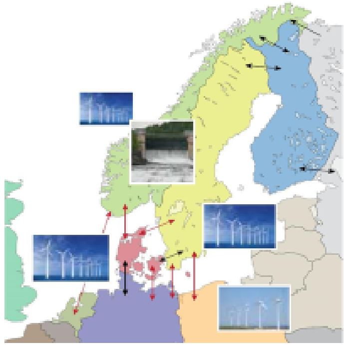


Presentation 11: Challenges and opportunities for PSH: Environmental and social perspectives - Stephen Sparkers



New Opportunities for Hydropower

- Pump storage is a known technology
- Synergy with intermittent wind and solar energy production
- Norway is in a unique position to become the "battery of Europe" due to potential storage and availability
- Boost and optimize renewable energy production in Europe through inter-connectivity and energy trading



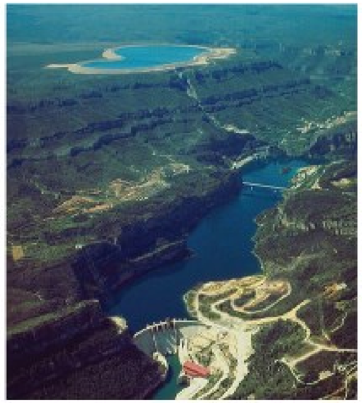
Challenges for E&S

- How to integrate E&S into the planning for PSH at an early stage to avoid high impacts or minimised
- Ensure that all impacts are mitigated and compensated in accordance with good practice and legal requirements
- Ensure good communication and stakeholder management processes: seeking acceptance

Impact – New Reservoir

Similar to Greenfield hydropower:

- Loss of land for food production or other uses local populations
- Resettlement and compensation for impacts on communities
- Loss of biodiversity and forests that could require replacement and offsets
- Potential resistance and opposition
- E&S impacts downstream – changes to original flows and production



La Muela on the Júcar River in SE Spain

Impact – Reservoir Fluctuation

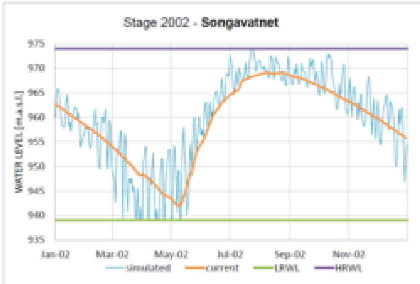


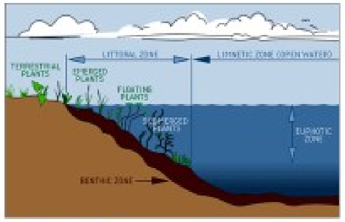
Figure 43 – Water stage, Songavatnet, 2002

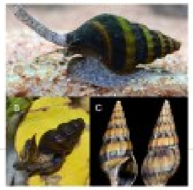
From Patocka, p. 58, NTNU thesis 2014

- Storage reservoirs modify and often reduce the range of seasonal variations
- Water level changes increase in frequency throughout the year
- Littoral zone impacted – erosion, landslides and bank slumping
- Safety issues may arise if communities located around the reservoir
- Steep and rocky banks less affected by fluctuations

Impact – Biological Loss and Exotic Species

- Drawdown areas may become "dead zones" absent of plants
- Loss of littoral animal species
- Spread of new species from downstream to reservoir
  - macro-invertebrates like crayfish, shrimp and snails
  - Concern about poisonous planktonic alga from fish farms in Norway
- Changes in species composition could lead to decrease in endemic species



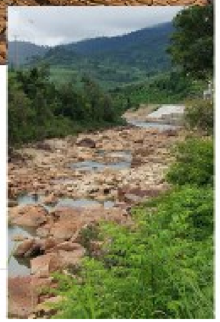


Impacts – Water Quality and Socio-Economic

- Aesthetic impacts if reservoir is used for recreational purposes and tourism
- Reduction in reservoir fisheries due to changes in water quality, temperature and turbidity
- In extreme cases bad odours from rotting vegetation and algae
- Potential increase in GHGs

Impact – Downstream

- Daily peaking regime could have increased impacts on downstream environment
- Water flow fluctuation
  - Increased erosion and bank slumping
- Water quality issues
  - Change in sediment loads
- Increased impacts on fisheries
  - Conditions changing daily
- Safety and access for communities
  - Constant changes in water levels



Location, Location, Location….

- Success for Starbucks Coffee is where outlets are located - the best locations are:
  - On busy corners
  - Near train and bus stations
  - In departure halls in airports
  - In large shopping malls
  - Near popular attractions

Location is key for Hydropower (PSH)

- Water availability for power production
- Proximity to demand – good prices for peak production
- Proximity to available cheap power for pumping
- Utilizing available hydropower systems or cascades
- LOW ENVIRONMENTAL AND SOCIAL IMPACTS

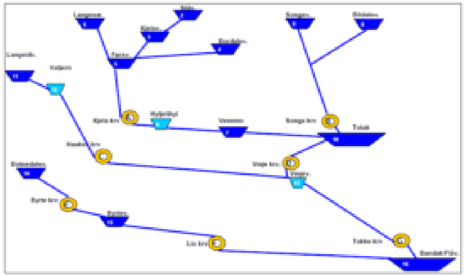


Figure 9 – Basic scheme representing Tokke-Vinje regulated system (30)

From Patocka, p. 23, NTNU thesis 2014

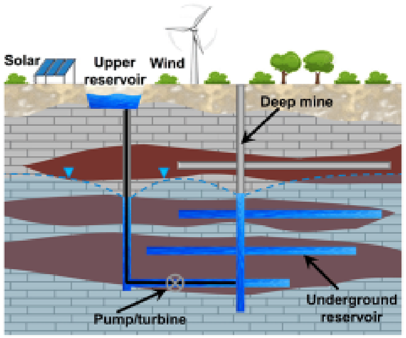
PSH vs. Batteries Debate

PHS	Batteries
+ volume/scale	+ smaller units
+ cost effective	+ limited impacts
+ reliable technology	
+ synergy with hydro	- raw materials
	- disposal/replacement
- large-scale impacts	- costs for large scale

- Complementarity of technologies
  - Positives for PSH at volume
  - Positives for batteries at small-scale
- Need both: choice depends of the grid requirements and locations
- Key E&S factor for PSH is site location:
  - Long narrow valleys, mining pits, underground locations, etc.
  - Low biodiversity values
  - Little resettlement or social impacts

Mitigation and Solutions

- Preferred options:
  - Reversible turbines and existing reservoirs
  - Use of underground storage (mines)
  - Part of a cascade system of plants
  - Long, narrow and steep valleys to reduce overall footprint
- Regulating ponds to ensure continuous downstream flows
- Avoid biodiversity impacts and complex offset mitigation
- Avoid resettlement and impacts on communities = acceptance



References:

- Immendoerfer, Andrea *et alis* "Life-cycle impacts of pumped hydropower storage and battery storage" in Int J Energy Environ (8: 231-245, 2017)
- Prasad, A.D *et alis* "Pumped Storage Hydropower Plants Environmental Impacts using Geomatics Techniques: An Overview" in Int. J of Computer Applications (81, 14, 2013)
- Patocka, Filip "Environmental Impacts of Pumped Storage Hydropower Plants", NTNU Trondheim, 2014

Presentation 12: Financing PSH projects - Nico Saporiti

Many financial products are available to finance the construction of Pumped-Storage Hydropower plants

Types of Finance	Source	Interest	Tenor
Concessionary finance grants or soft loans	Bilateral sources or multilateral development agencies; carbon credits	Very low interest rates	Long term
Public equity	Public investment (Government supported). At times public equity is indirectly funded through bilateral/multilateral development banks	Dividends can start low and increase over time	Indefinite
Public debt	Loans from the Government, public bonds or multilateral development banks	Low; interest rate set by Government or Development Banks	Medium to long-term with optional grace period
Export credit	Finance through Export Credit Agencies	Medium to high	Variable but commonly short to medium term
Private commercial debt	Private banks, commercial arm of Development Banks	High interest (may be lower in presence of a guarantee)	Short to medium term (possibly extended with guarantees)
Private equity	Private sponsors, private investors, commercial arm of Development Banks	High dividends are expected for risk compensation	Depends on length of concession

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2

IFC, part of the World Bank Group, specializes on Subnational and "Private-sector" products (1/2)

- Sovereign loans
- Political insurance guarantees
- Partial risk / credit guarantees
- …

- Subnational loans

- Corporate Debt
- Equity
- Project Debt
- Advisory …

IFC, part of the World Bank Group, specializes on Subnational and "Private-sector" products (2/2)

- Corporate Finance
  - Banks lend to the developer – normally a large Corporate - which will implement the project;
  - Corporate is responsible for debt service (multiple revenue streams?);
  - Credit Assessment is not focused on what the debt will be used for but rather on the overall ability of the Corporate to service the interest and to repay the debt.

- Project Finance
  - Bankability assessment focuses on project-specific cash-flows, rather than the collateral / creditworthiness of the developer;
  - Project Company repays the interest and capital from the free cash available to service the debt;
  - Project Company assets may serve as collateral to reduce the risk of the sponsor (e.g. proceeds of sales agreements (off-take agreements), a pledge of shares in the project company…).

World Bank Group's "cascade approach" (1/2)

- A "cascade approach" to investment decision-making to encourage private sector participation, while leveraging and preserving scarce public dollars for critical public investments.
- If commercial financing is available, that is the preferred course.
- If it is absent, we try to address market failures.
- If those efforts are unsuccessful, we use utilize risk instruments and our own matching capital to try to encourage private investment.
- Finally, other private-sector based solutions are not viable, public and concessional financing will be used.

World Bank Group's "cascade approach" (2/2)

- <u>In any case</u>, the proposed PSHPP projects need to be backed by solid evidence that they offer the **least-cost solution** to meet the storage, peaking power and ancillary services needs of the respective electricity systems.

IFC has worked as Transaction Advisor on two PSHPPs

- India: Upper Indravati (~600MW)
- North Macedonia: Cebren (~300MW)

Enough with the advertising … now the turbulent part!

IFC's activities as Transaction Advisor on the two PSHPPs projects

Both projects:

- To be developed under a PPP model;
- Feasibility assessment and commercial / legal structuring ongoing.

Financing decision – key risks (1/2)

- Energy Market risk:
  - Tariff level;
  - Peak-off peak Tariff spread.
- Capacity Market risk

Revenues

- Construction Cost Risk:
  - 30+% risks for HPPs, mostly liked to underground work.
    - Could be less for PSHPP from existing reservoirs.
- Seasonality dynamics:
  - Resource / demand / market risk
- Debt service is highest during initial years
  - grace periods and tenors need to be maximized and the government may defer its dividends, royalties or taxes to mitigate this risk.

Financing decision – key risks (2/2)

- Hydrological risk:
  - Less important than in hydropower plants – important for bankability
    - determines the income generated / availability payments
  - Need for reliable data
- Permitting risk/Political risk:
- Payment default:
  - off-taker (utility, TSO) might not be able to hold payment obligations
  - Escrow account with a minimum holding or Government guarantees ca mitigate this risk
- Local currency devaluation:
  - If the financial market is not developed enough to provide for formal hedging, the risk has to be borne by the project company.

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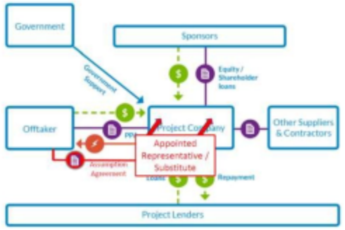
Dams have essentially no value as "collateral"

- Like all immoveable assets, dams are … worthless as collateral without an enforceable contract that provides for a secure stream of revenues.
- It is necessary to take security over them, mostly as a defensive measure.
- Lenders address these issues in the Direct Agreement.



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Choosing the correct business model one of the most important considerations to ensure project bankability

Three main business models:

1. Utility-owned;
2. Capacity contracts;
3. Merchant.

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1. Utility owned: corporate financing

- Utilities are investing in energy storage to defer the cost of electrical T&D upgrades needed to meet growing electricity demand.
- PSHPPs can help improve grid reliability by managing T&D congestion and improving T&D performance, allowing utilities to increase the lifespan of infrastructure assets and to avoid purchasing additional equipment.
- Bankability considerations:
  - project needs to be a no-regret solution;
  - good credit / borrowing capacity of the utility (i.e. ability to repay the loan based on pooled revenues).

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2. Capacity Contracts (often as Public Private Partnership)

- Capacity contracts involve utilities procuring energy storage-as-a-service from providers that offer reliable load reduction (ideally in location where there are capacity constraints).

- Bankability considerations:
  - Payment structure likely need to be based on a “fixed” annuity-type payment linked to actual availability of the plant.
  - Lenders would want to be satisfied with:
    - the experience and financial capacity of the PSHPP developer,
    - the technical competence the EPC contractor, and
    - the credit quality of the offtaker.

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3. Merchant model: the most challenging to project- finance

- PSHPP owners and operators to unlock revenue streams through participation in competitive electricity markets, including ancillary services markets.
- The merchant plant owner can also establish a power purchase agreement with a utility, or directly with other electricity end users, to provide services at specific times.

- Bankability considerations:
  - Only model in which electricity market risk is not diversified;
  - Need to forecast electricity prices and peak/off-peak spread;
  - Uncertainty over future revenues may result in:
    - lower debt to equity ratios;
    - need for guaranteed revenues to “anchor” debt repayment;
    - recourse to shareholders (no pure Project Financing).

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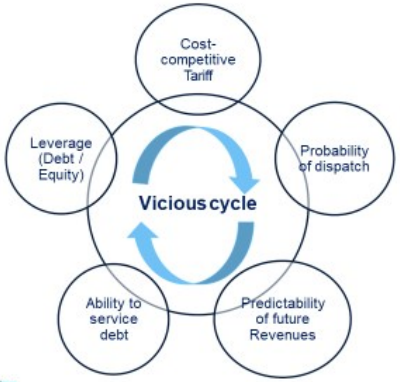
The capital structure can influence the cost- competitiveness of any power generation project



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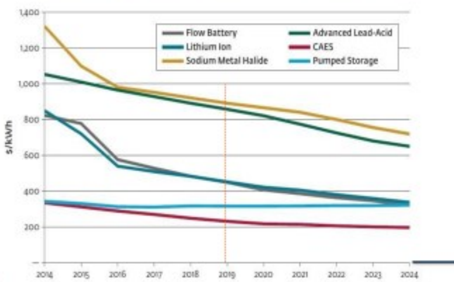
And finally, the part where I get kicked out of the workshop …

IFC

A bankable PSHPP needs 15+ years of guaranteed cash-flows. Would you accept 15+ years of technology risk?

- Forecasts of continued decline in solar PV prices also anticipate a similar drop in energy storage costs, especially for Li-ion batteries, as well as the potential for major energy storage technology breakthroughs with substantial cost advantages.

Utility-Scale Energy Storage System Cost Trends by Technology, Global Averages: 2014–2024



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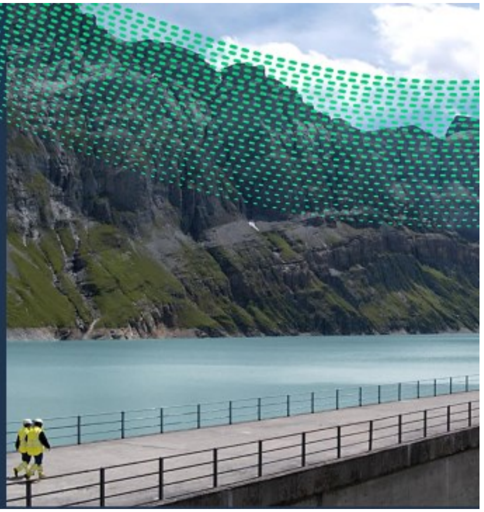
Presentation 13: PSH: Transitioning to a renewable, cheaper and more reliable electricity supply

PUMPED HYDRO STORAGE

Transitioning to a renewable, cheaper and more reliable electricity supply



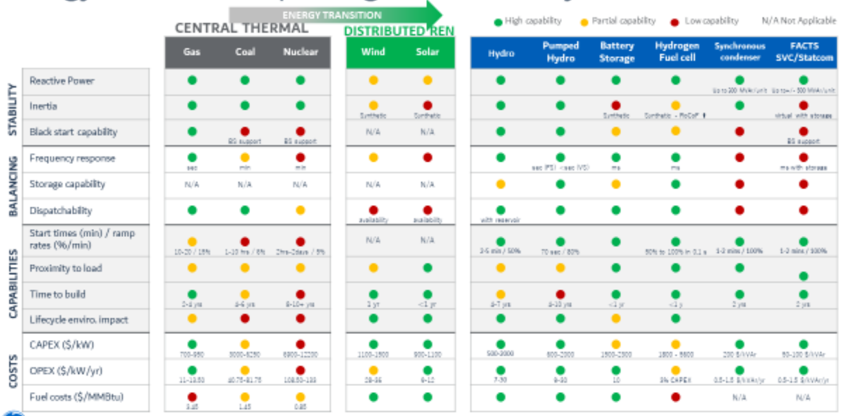
Agenda

- Energy transition and Grid challenges
- Hydropower as enabler of renewable transition
- Pumped Hydro Storage's unique capabilities
- Costs overview and project optimization

GE Renewable Energy

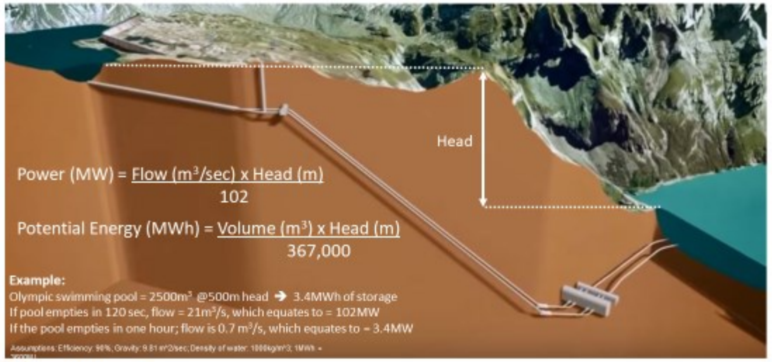
2

Energy transition impacting Grid reliability



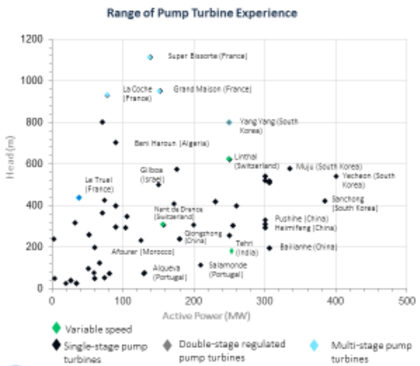
Pumped Hydro Fundamentals

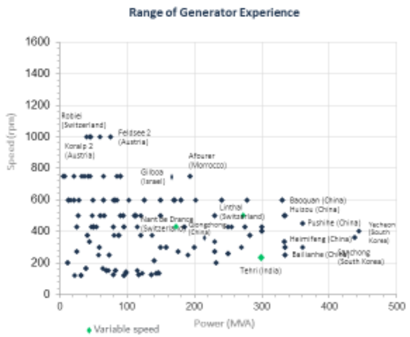
High Capacity, Long Duration, Long Lived 'water batteries'



Large range of expertise and experience

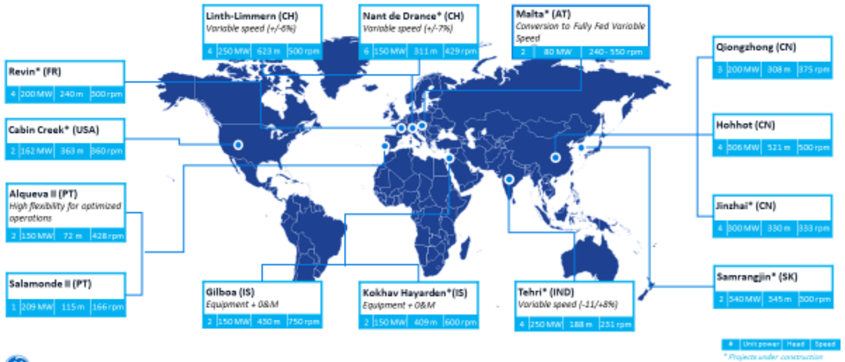
Covering a wide range of head, speed and power





Key PHS References

Currently adding ~4 GW of GE's hydro storage projects - incl ~2 GW with variable speed technology



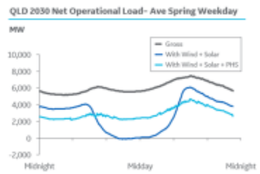
The role of pumped hydro

How pumped hydro can help enable renewable transition

- **Long duration storage** to 'smooth' renewable output in the medium and long term
- **Reduced peak prices** and hence overall electricity price in the near term
- Additional **system strength**
- **Ancillary services**
- A **renewable way to firm wind and solar**
- **Reduced transmission investment** costs
- **Jobs** and investment in regional areas

Australia's Queensland example

Smooth renewable output

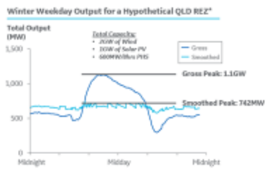


Pumped hydro could help make renewable output smooth and predictable

Reduced peak prices

By 'shaving the peak', pumped hydro can provide significant savings for QLD consumers

Reduce transmission investment costs

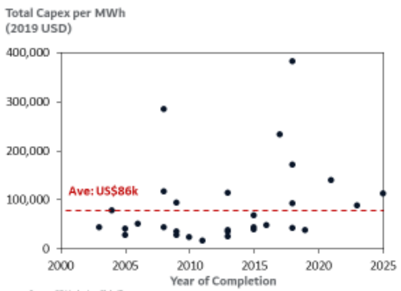


By smoothing output within a REZ, pumped hydro can reduce cost to connect the REZ

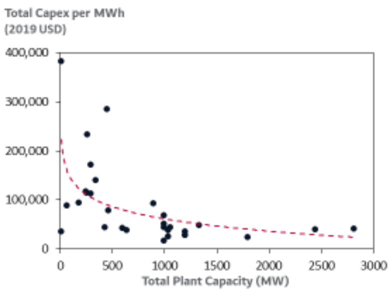
Understanding Pumped Hydro Capex

Capital costs of pumped hydro projects around the world

Capex by Year of Completion



Capex vs Total Plant Capacity



Source: GE Marketing, GlobalData
Notes: Active, Under Construction or Announced projects; Prices escalated according to inflation; 31 projects with available data

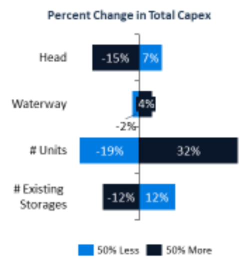
Understanding Pumped Hydro Capex

A worked example

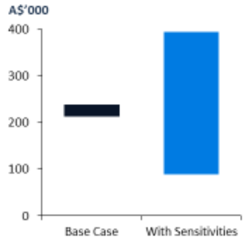
Hypothetical Project Data

Capacity	2x 125MW
Duration	10 hours
Head	250m
Waterway	1250m
Upper Res	Turkey Nest
Lower Res	Existing reservoir

Key Sensitivities



Est. Total Capex per MWh Installed

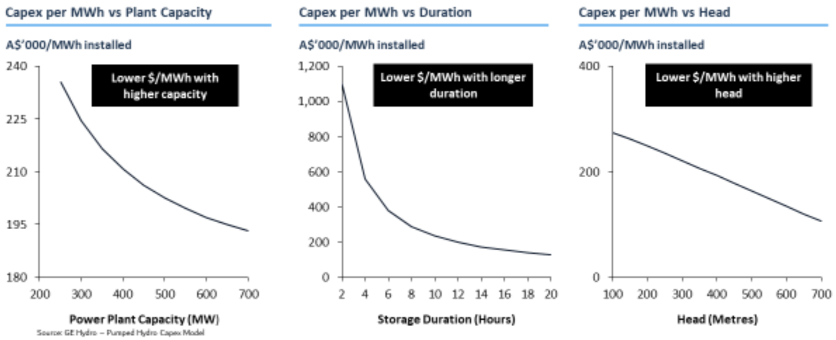


Source: GE Hydro – Pumped Hydro Capex Model

Site fundamentals (and hence site selection) is key!!!

Understanding Pumped Hydro Capex

Economies of scale, duration and head



Source: GE Hydro – Pumped Hydro Capex Model

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Understanding Pumped Hydro Capex

Key considerations for developers and investors

Site Selection Considerations

- **Water:** ideally use one or more existing storages
- **Head:** ideally 200-600m (~the higher the better)
- **Waterway:** ideally length <10x the head (the lower the better)
- **Grid Connection:** ideally <20km from transmission (the lower the better)
- **Site Access:** ideally <20km from roads (the lower the better)
- **Land use:** environmental and cultural considerations

Source: GE Hydro Analysis

Project Design Considerations

Mainly OEMs

- What **type of equipment** should be used? Fixed vs variable speed, etc
- Over **how many units** should the capacity be spread?
- What should **capacity and duration** be?
- What should the **powerhouse position** along the waterway be?
- Overland vs underground **waterway**?
- What should the **powerhouse type** be (shaft vs cavern)?
- What is the optimal **siting and shape** of the reservoirs?

Mainly Civils

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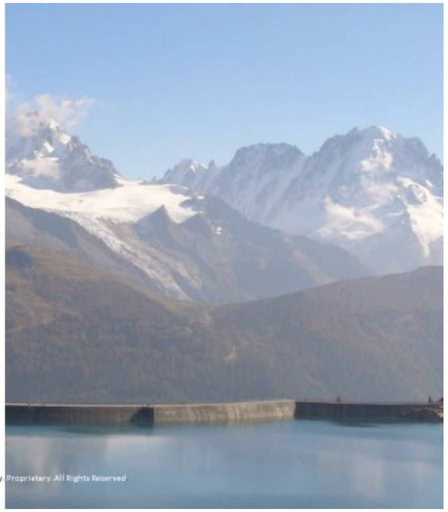
Hydro needs to remain on top of Regulators' agendas

- **Simplify licensing/permitting** process to reduce lead time and development costs
- Give stable investment signals with long-term **remuneration visibility**
- Better recognize and **reward services provided to the Grid**
- Valorize **multi-purpose water** use (irrigation, flood control, drought)

To ensure a smooth energy transition, Hydro business model must evolve



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Thank you!

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APEC Project: APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply

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