Advanced Energy Partnership for Asia

Integrating Variable Renewable Energy in Power Systems:

Fundamentals for the Greater Mekong Subregion

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National Renewable Energy Laboratory (NREL)

Mekong for the Future: Second Regional Energy Workshop

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Section 1: Overview of VRE Integration

Introduction to USAID-NREL Partnership

Opportunities and Challenges with Increasing VRE Levels

Solutions for Managing Increasing VRE Levels

Decision-Making Tools: RE Data Explorer

Image: iStock

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Advanced Energy Partnership for Asia

The Advanced Energy Partnership for Asia

USAID has partnered with the U.S. Department of Energy's national laboratories to support Asia EDGE, or Enhancing Development and Growth through Energy, and the growth of sustainable and secure energy markets across Asia.

This collaboration, **the Advanced Energy Partnership for Asia**, is led by USAID and the National Renewable Energy Laboratory (NREL) and helps partner countries by conducting research, analysis, and capacity building to deploy advanced energy systems (e.g., renewable energy, energy efficiency, energy storage, electric mobility, microgrids, distributed energy, energy security and resilience, etc.).

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What We Do

Utility Performance

Improve energy utility planning and operational practices to increase advanced energy system implementation

Data-Driven Decision-Making

Increase the use and availability of high-quality data to drive energy sector analysis and decision-making

Level Playing Field

Assist governments in fostering more supportive policy, legal, and regulatory environments for private sector deployment and investment in advanced energy systems

Regional Integration

Advance regional energy system planning and operational practices for efficient cross-border energy trade

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The USAID-NREL Partnership's global technical platforms provide free, state-of-the-art support on common and critical challenges to scaling up advanced energy systems.

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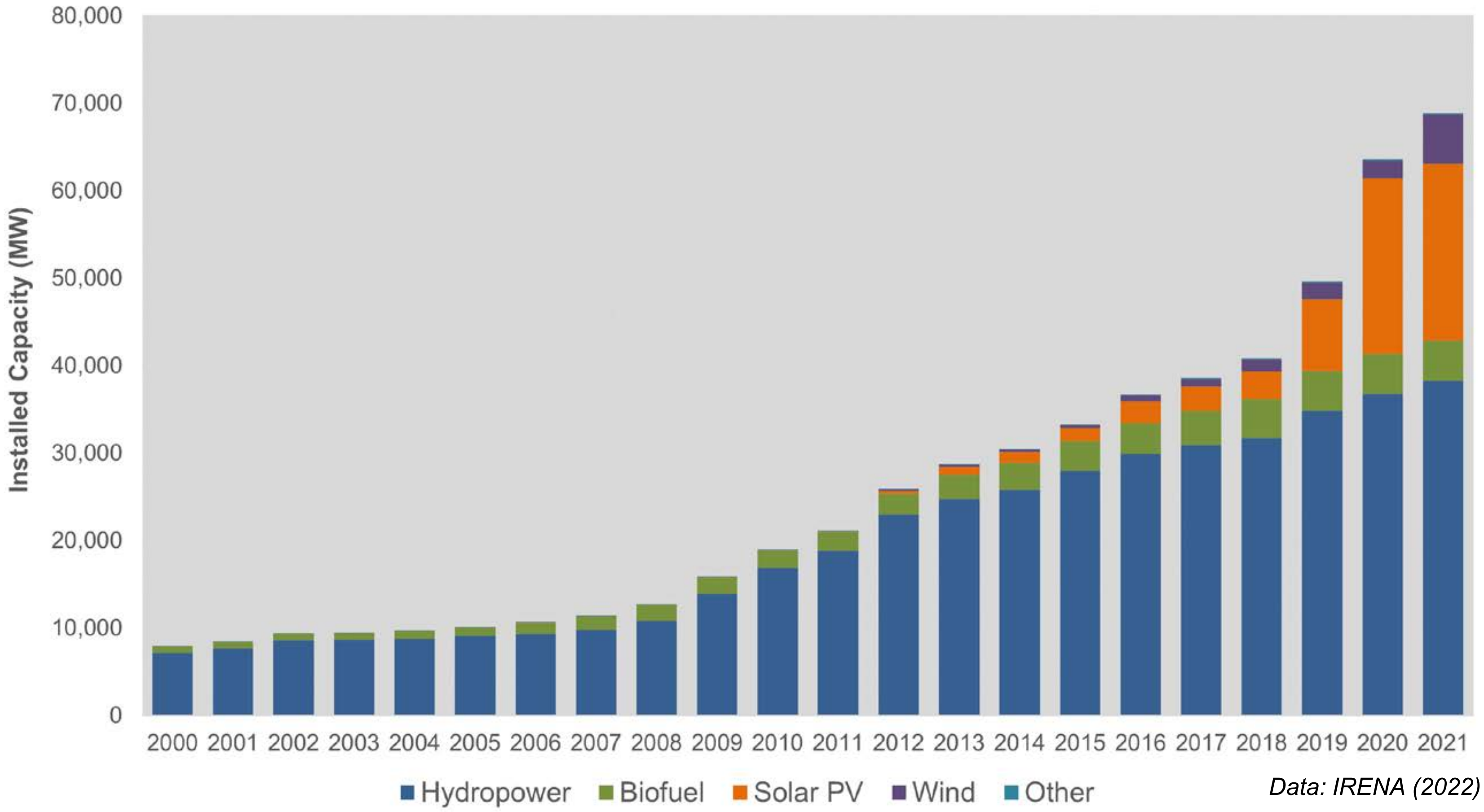
Global and Regional RE Capacity Growth

- Renewable energy (RE) generation capacity represents the majority share of new additions globally.
- Global renewable generation capacity at the end of 2021 was 3,064 GW.
- Solar and wind accounted for 88% of new RE capacity in 2021.
- 60% of new renewable capacity installed in 2021 was in Asia.

Source: IRENA (2022)

Figure. Installed capacity of RE in the Greater Mekong
(Cambodia, Laos, Myanmar, Thailand, Vietnam)



Data: IRENA (2022)

Note about the dataset: "Other" refers to geothermal, marine, renewable municipal waste, and solar thermal energy; "wind" refers to onshore and offshore wind; "biofuel" refers to biogas, liquid biofuels, and solid biofuels; "hydropower" refers to mixed hydropower, renewable hydropower, and pumped storage hydropower.

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Why Renewables?

- Meet government goals and targets
- Low-cost option to serve growing demand and to diversify the legacy thermal generation mix
- Pollution reduction and health benefits
- Support energy access
- Energy security and resilience
- Job creation and economic growth

	MITIGATION TYPE	TYPE OF COVERAGE	SECTORAL SCOPE	MITIGATION TARGET	MITIGATION DETAILS
Cambodia	Relative emission reduction	Economy-wide	Energy, Agriculture, Transport, Waste, LULUFC, Industry	41.7% reduction in GHG emissions	By 2030, forestry and other land use (FOLU) is expected to reduce emissions by roughly 64.6 million tonnes of CO_2 equivalent ($MtCO_2eq$)/year under the NDC scenario (41.7% reduction, of which 59.1% is from FOLU).
Lao PDR	Relative emission reduction	Economy-wide	Energy, Agriculture, Transport, Waste, LULUFC, Industry	60% reduction in GHG emissions (unconditional)	Unconditional aim for 2030: 60% reductions in GHG emissions relative to the baseline scenario, or approximately 62 000 kilotonnes of CO_2 equivalent ($ktCO_2eq$) in absolute terms.
Myanmar	Policies and actions	Sectoral	Energy, AFOLU (agriculture, forestry and other land use) (Myanmar aspires in the NDC to further engage in other sectors to establish a base for setting an economy-wide target in the future)	Emissions reductions contributions by 244.52 million tCO_2eq (unconditional), and 414.75 million tCO_2eq (unconditional) by 2030	Total emissions reductions are 244.52 $MtCO_2eq$ unconditionally, and a total of 414.75 $MtCO_2eq$ conditionally by 2030. In the energy sector, a conditional target of avoiding 144.0 $MtCO_2eq$ emissions by 2030 compared to BAU by increasing the share of renewable energy (solar and wind) to 53.5% (from 2 000 megawatts [MW] to 3 070 MW) by 2030, and decreasing the share of coal by 73.5% (from 7 940 MW to 2 120 MW) by 2030.

Figure. Government goals for select Greater Mekong countries

(Not shown: Thailand and Vietnam)

Source: IRENA and ACE (2022)

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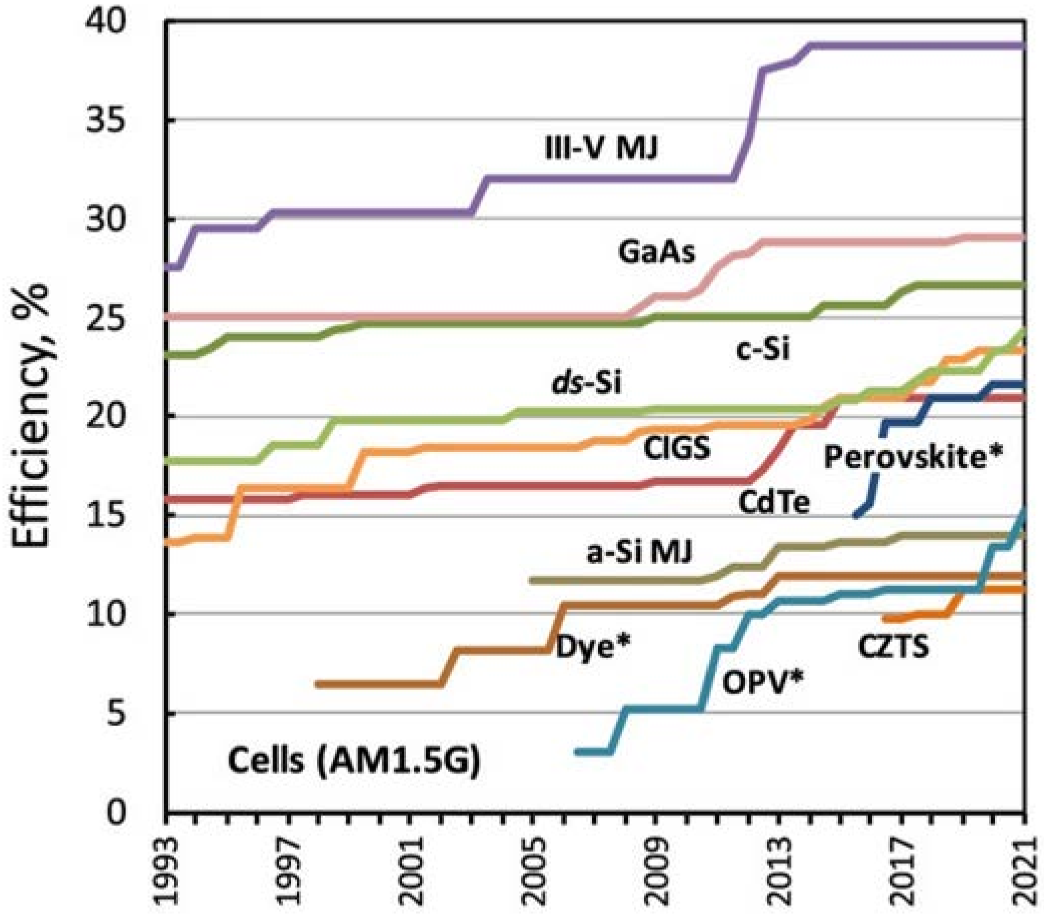
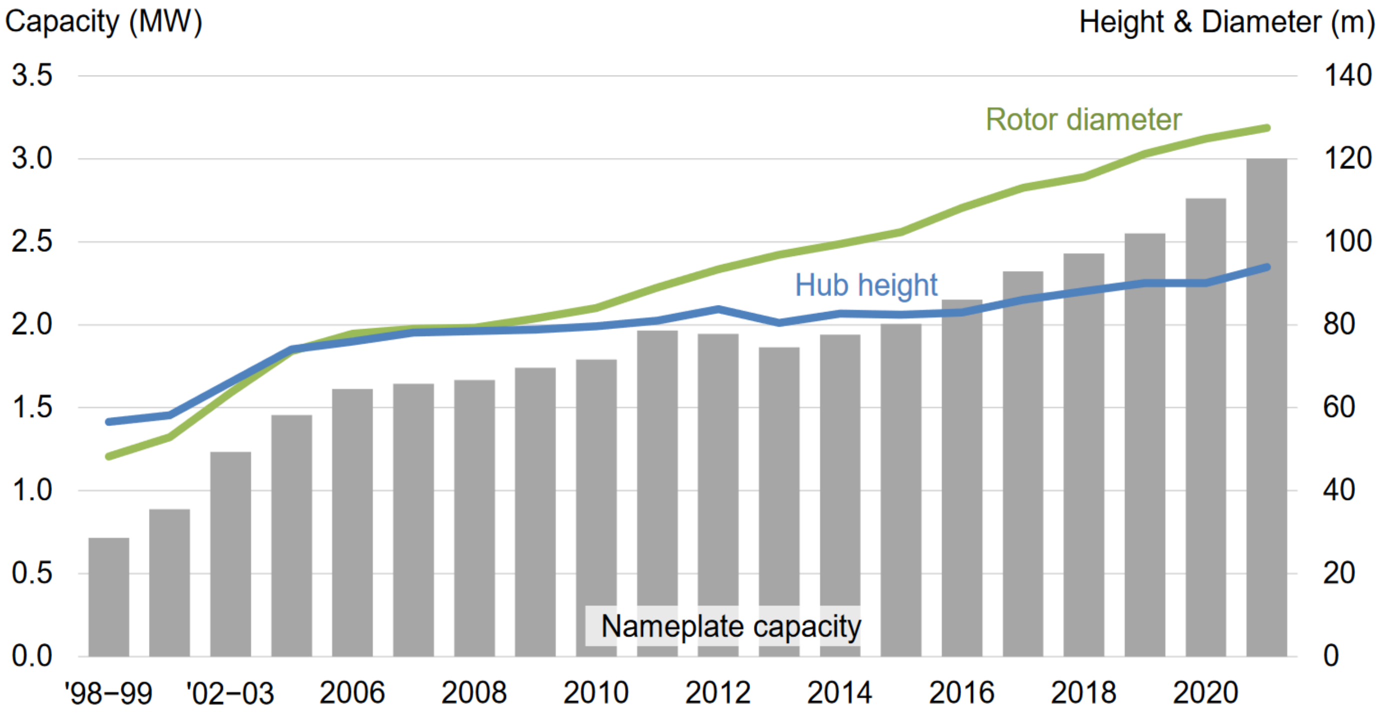
Advances in RE Technology

Figure. Highest confirmed efficiencies for different solar photovoltaic (PV) cell technologies



Source: Green et al. (2020)

Figure. Average turbine nameplate capacity, hub height, and rotor diameter for land-based wind projects in the United States



Source: Wiser et al. (2022)

2021: Vietnam had the largest turbine rotor diameters, on average.

Source: IRENA (2022)

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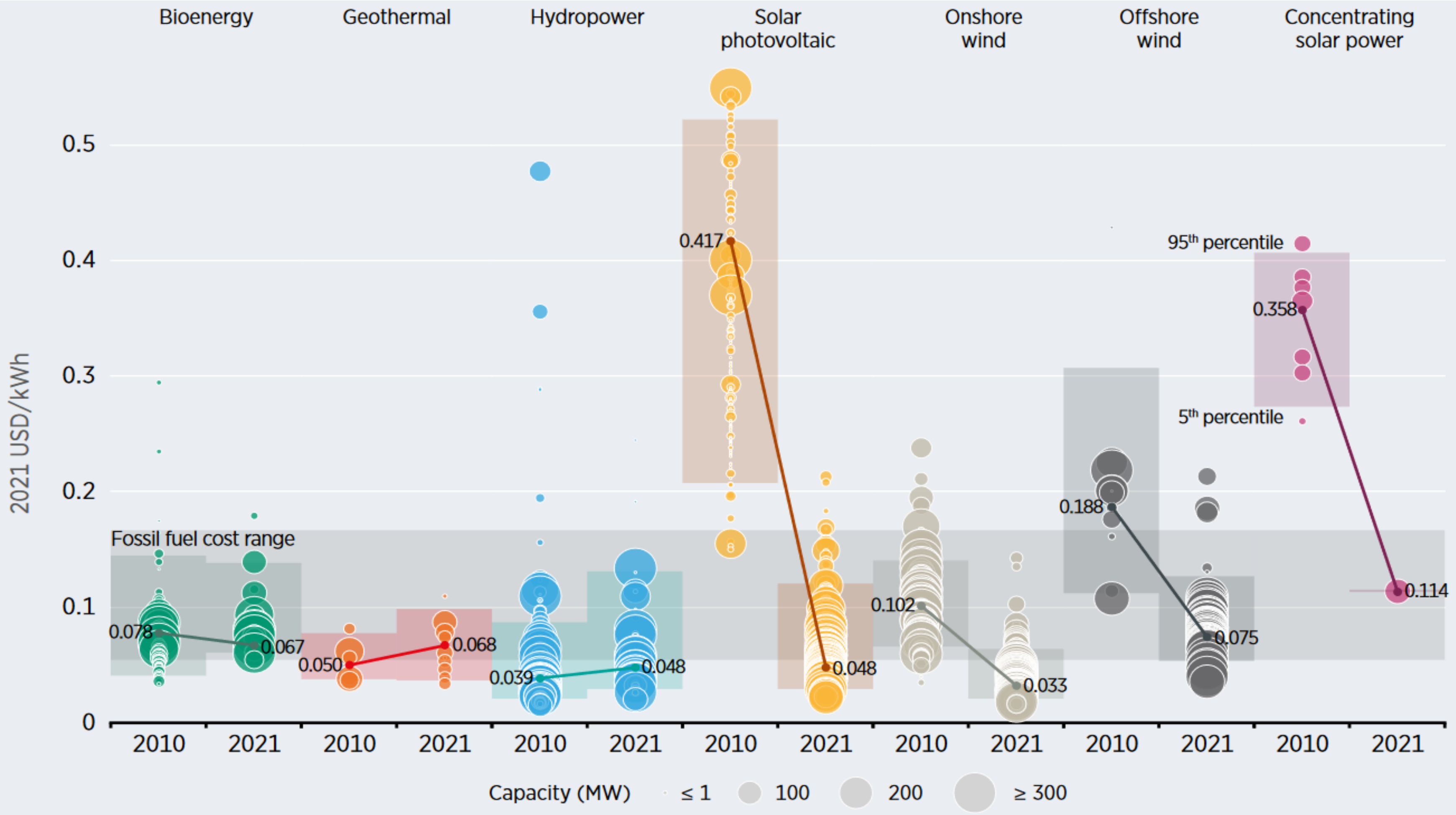
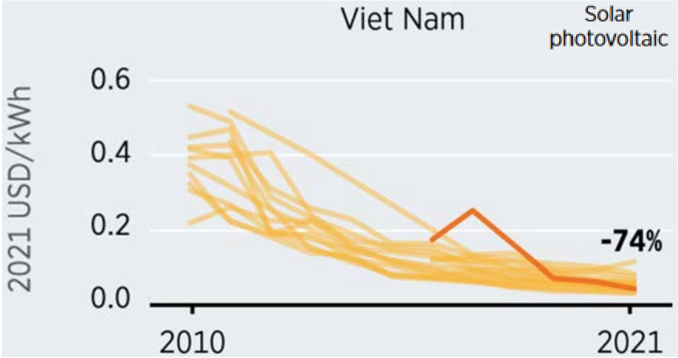
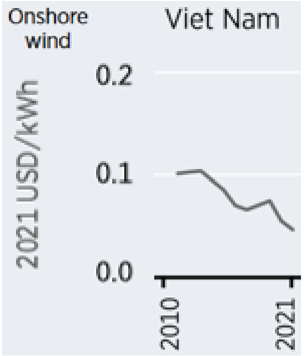
Falling Costs of RE Generation

Figure. Global weighted average LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2021







Source: Taylor et al. (2022)

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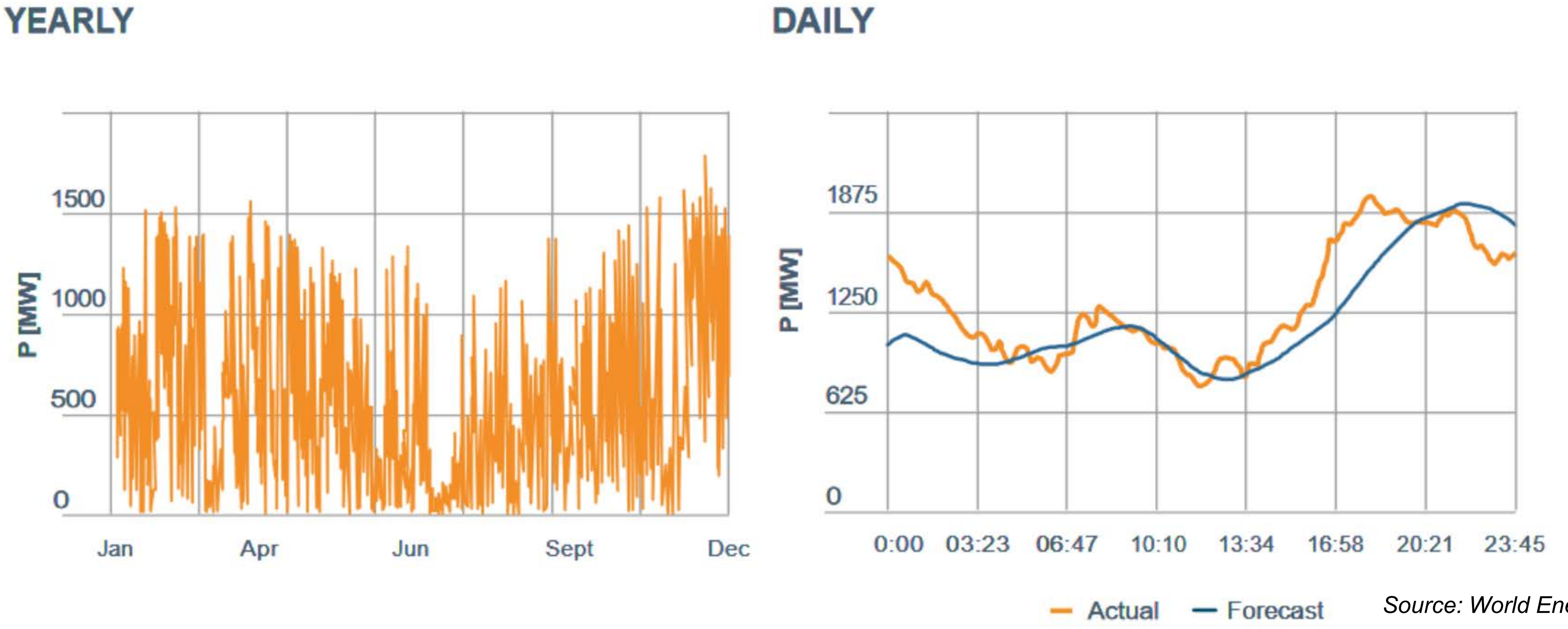
Variable RE (VRE) Characteristics

- **Variable:** generator output varies with the intensity of the energy source (sun or wind).
- **Uncertain:** wind and solar generation act similar to “load” in the power system, and actual power output is different than forecasted output.
- **Nonsynchronous:** does not provide inertial response.

Figure. Yearly and daily variability of wind fleet power production in Ireland



Source: World Energy Council (2016)

Grid Planning and Operation Considerations

RE is variable, uncertain, and nonsynchronous, raising new considerations for grid planning and operations.

1. System balancing requires more flexibility.
2. The need for operating reserves can increase.
3. More transmission and changes in planning are needed.
4. Existing thermal assets are used less frequently, affecting cost recovery.
5. Voltage control and inertia response come at an added cost.

Image. NREL researcher demonstrating software to manage high renewable energy in power systems

Image: Werner Slocum (NREL)

Source: USAID Clean Power Asia

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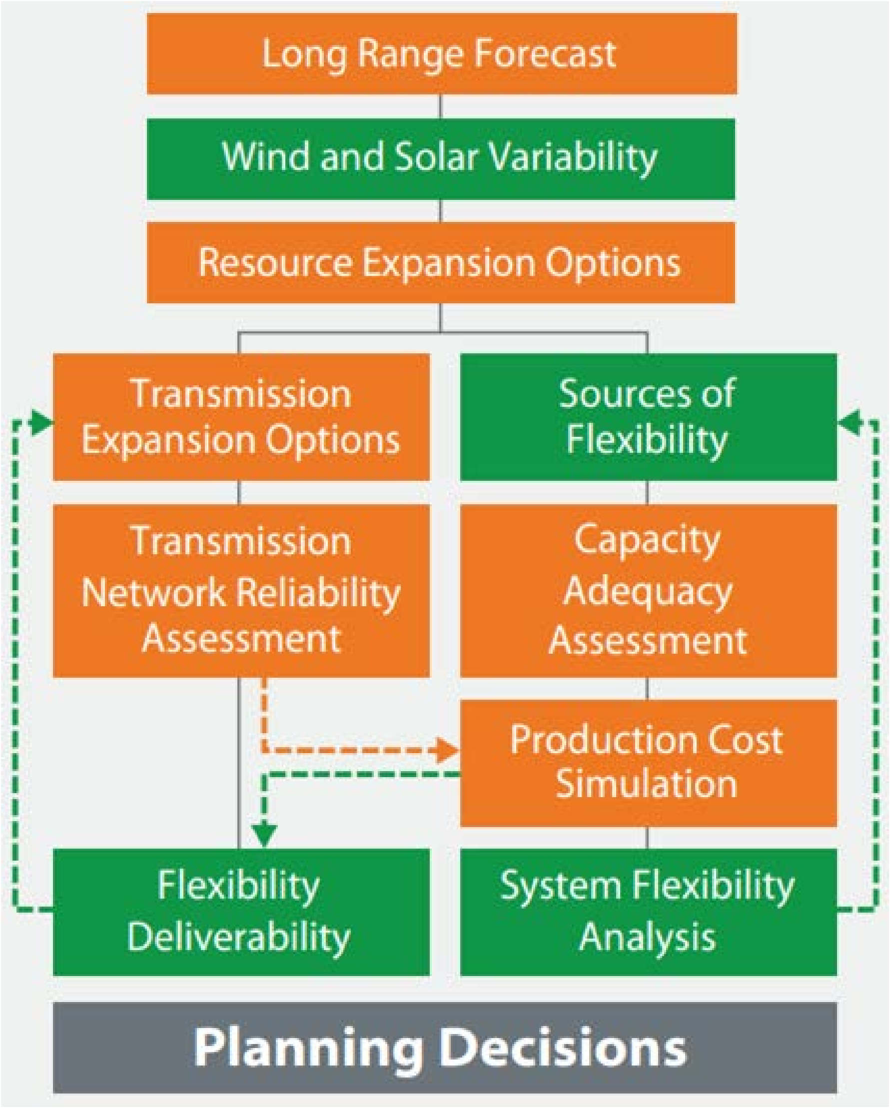
Changes in Power System Planning

Figure. Planning framework for facilitating higher levels of VRE into power systems



Green Boxes = new steps for power system planning with variable RE

Source: Milligan and Katz (2016)

Case Studies: Grids With High RE Levels

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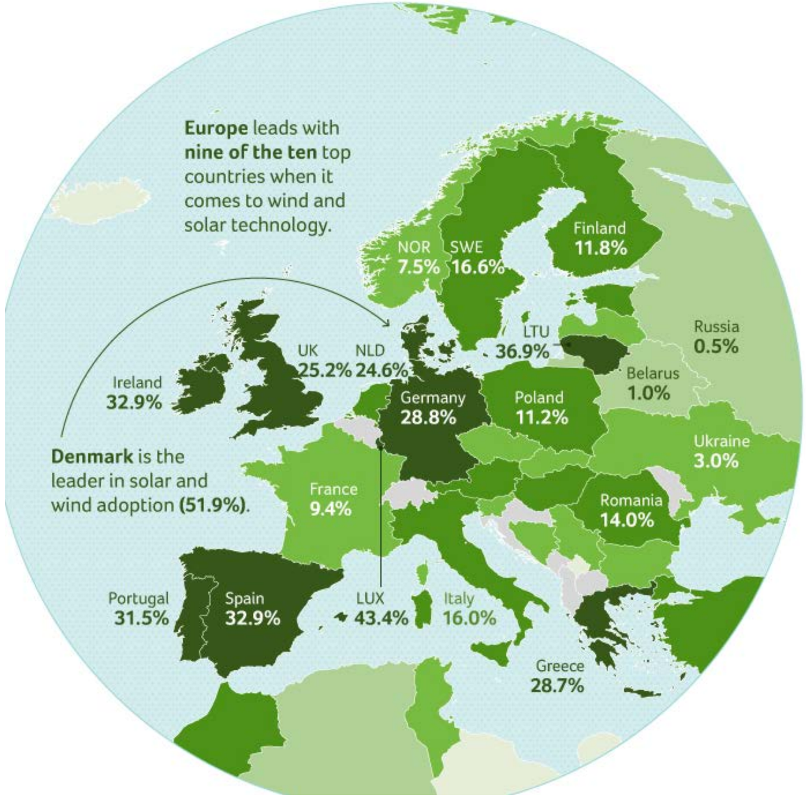

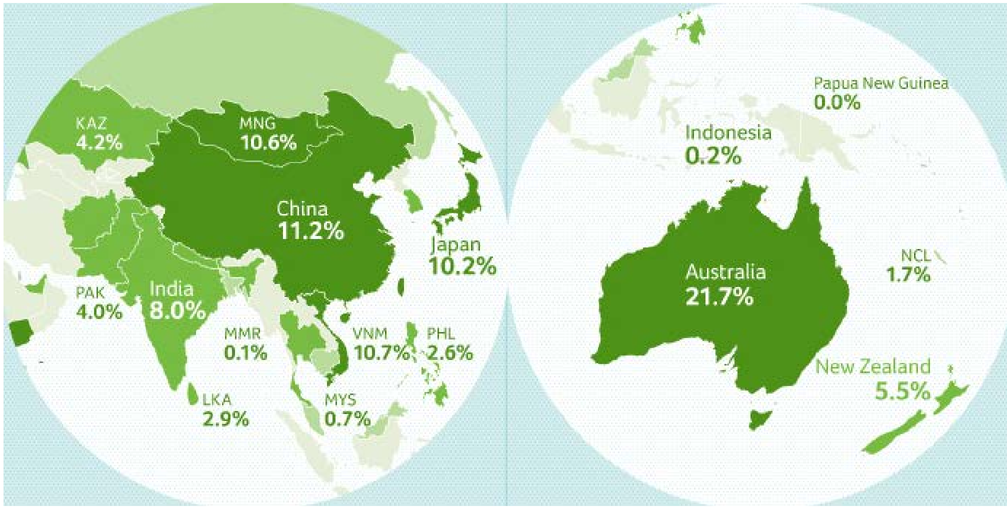

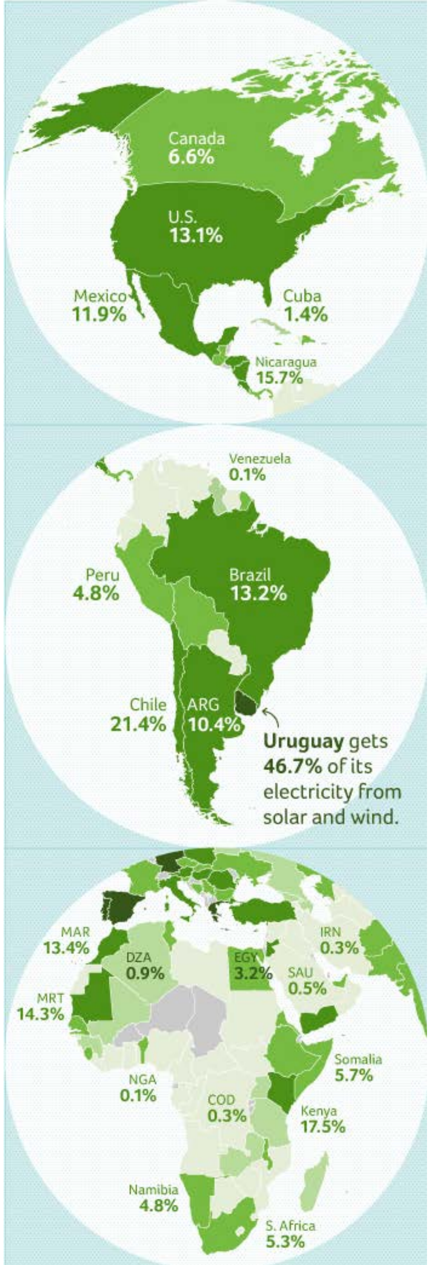

Figure. Percentage of wind and solar in electricity generation mix by country in 2021

Source: Venditti (2022)

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Does Variable RE Generation Require Backup by Conventional Plants?

- Reserves are already a part of every power system.
- Individual plants do not require backup:
  - Reserves are optimized at the system level.
- Wind and solar could increase the need for operating reserves:
  - These reserves can often be provided by other generation that has turned down to accommodate wind and/or solar.
  - The need for these reserves is not a constant (depends on wind and/or solar resources).
  - Many techniques are available to reduce the quantity of needed reserves.
- Wind and solar can also provide certain reserves.

Image. Natural gas power plant

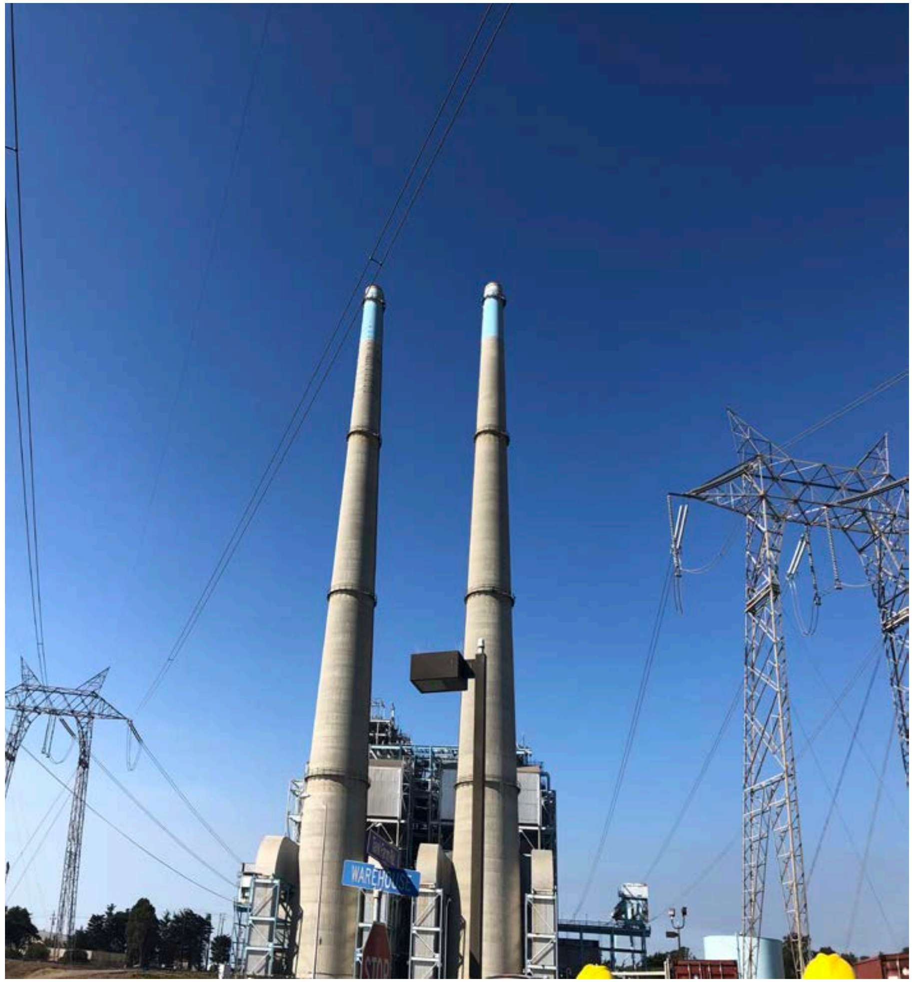

Image: Prateek Joshi (NREL)

Does Variable RE Require Storage?

- Storage is always useful (even without RE) but not always the lowest-cost flexibility option.
  - There are other options to provide system flexibility.
- Interconnected power systems can safely and reliably integrate high levels of variable RE generation without new energy storage resources.
- Storage is not necessary for VRE integration in all systems.
  - The need for storage is system-specific.
  - With the rapid decline in storage costs, storage could be valuable in systems with or without RE.

Image. Battery energy storage

Image: Werner Slocum (NREL)

Summary: RE Opportunities and Challenges

- Benefits from trends in RE technology improvements and cost reductions.
- Importance of planning and target setting for increased RE deployment.
- New considerations for grid planning and operations with RE integration.
- Actual operating experiences from around the world have demonstrated that up to ~50% annual RE generation levels are achievable today (e.g., Denmark).
- Specific backup generation and storage is not necessarily required, but additional reserves may be needed with high RE levels.

Image. Solar PV plant in Laos

Image: NREL

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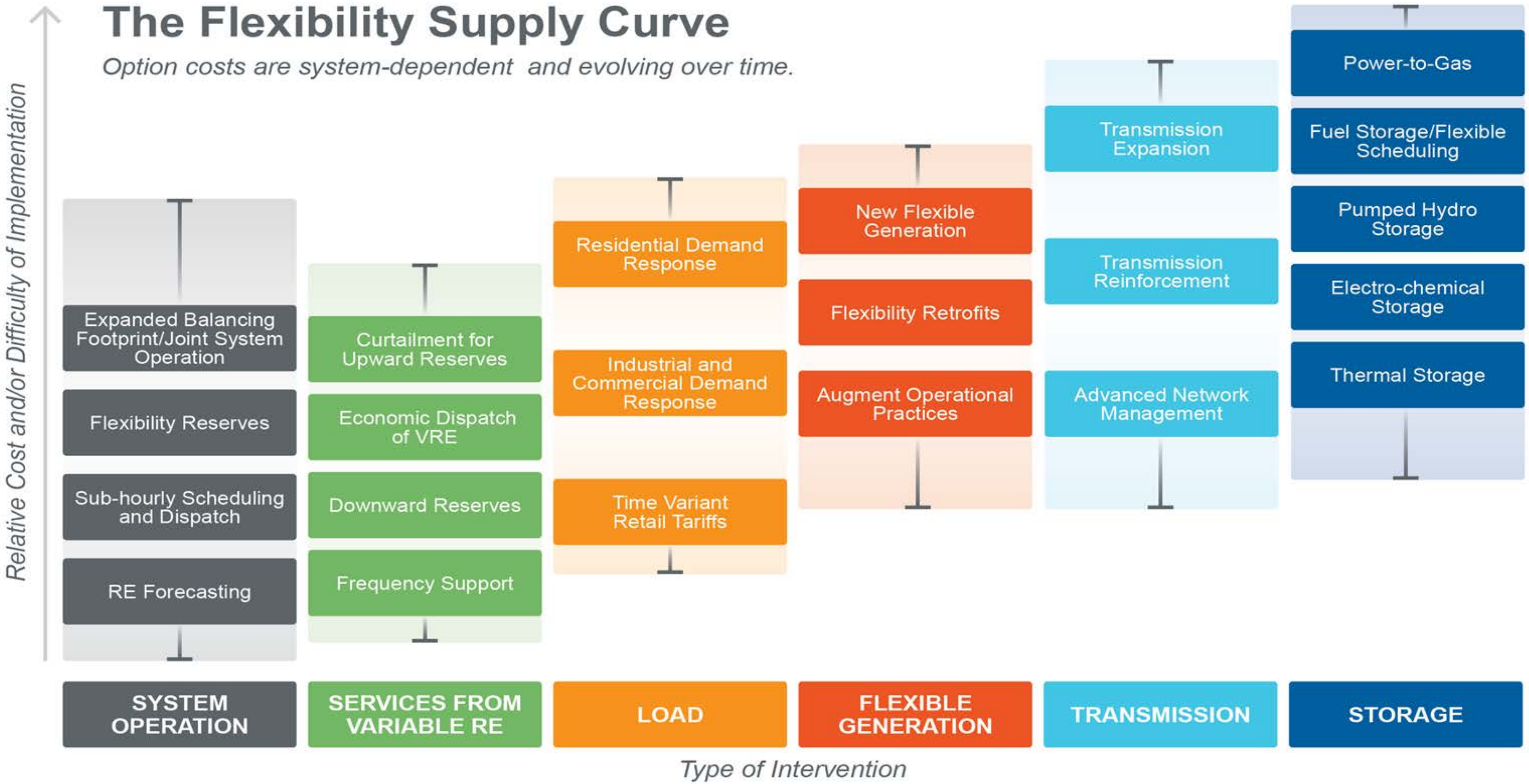
Options To Manage RE Integration

Figure. Different options to increase grid flexibility and integrate VRE

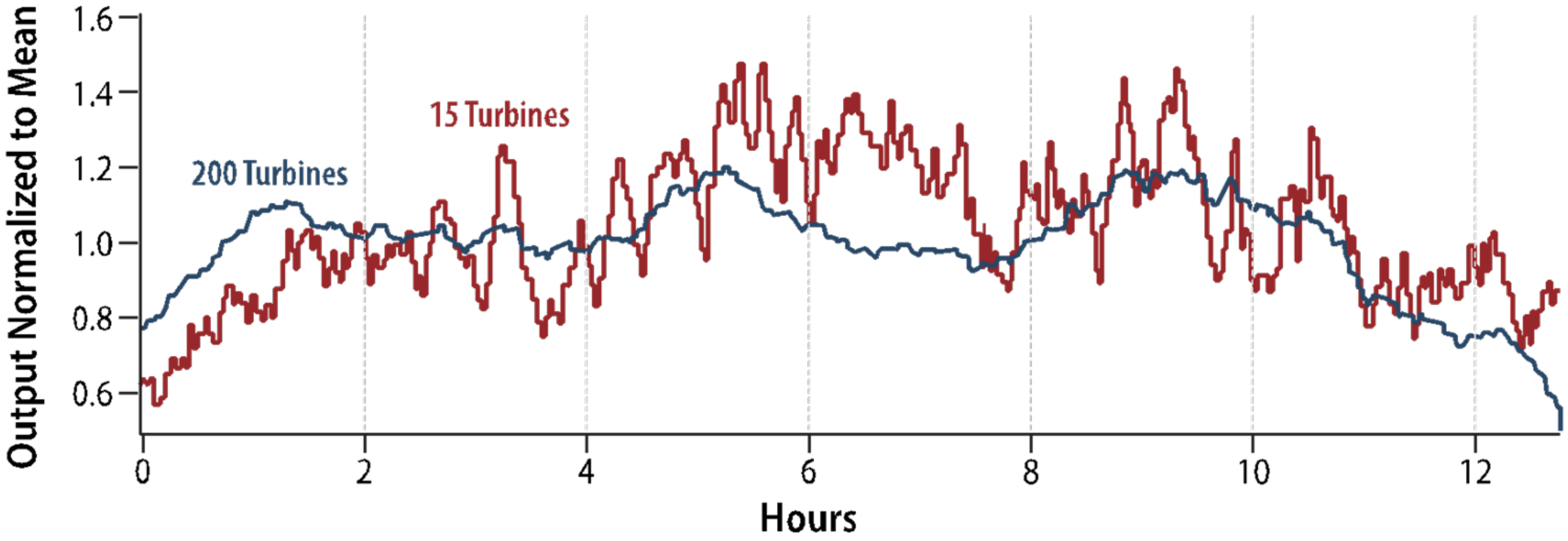


Source: Blair et al. (2022)

Geographic Diversity of VRE Resources

Geographic diversity of VRE (wind and solar) can reduce overall generation variability and the need for reserves.

Figure. Power output of 200 wind turbines vs. 15 wind turbines



Geographic dispersion can reduce the need for operating reserves because the aggregate output is moderated. Expanding the balancing area footprint through reduced transmission constraints or cross-border trade can also help.

Source: Denholm and Cochran (2015)

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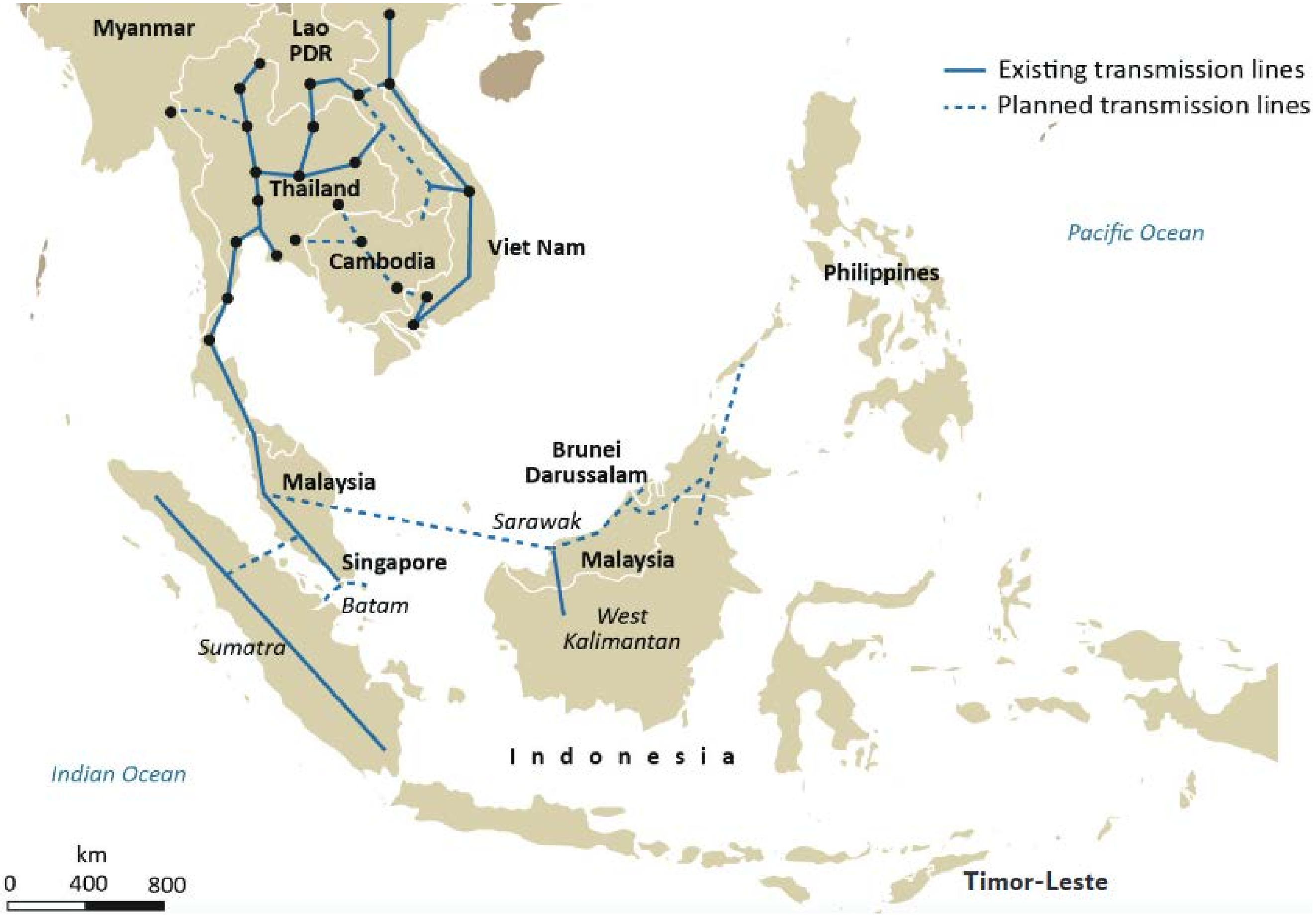
The Role of Cross-Border Trade

Figure. Existing and planned transmission within the Greater Mekong and Southeast Asia



Source: ADB (2022)

Power trade can expand the geographic diversity of the balancing area to support RE via:

- Larger pool of resources
- More diverse set of generation characteristics
- Seasonal and diurnal optimization of power provision
- Access to clean but non-native resources (wind, hydro, land, etc.)
- Access to low-cost generation options

Flexibility From Existing Thermal Power Plants

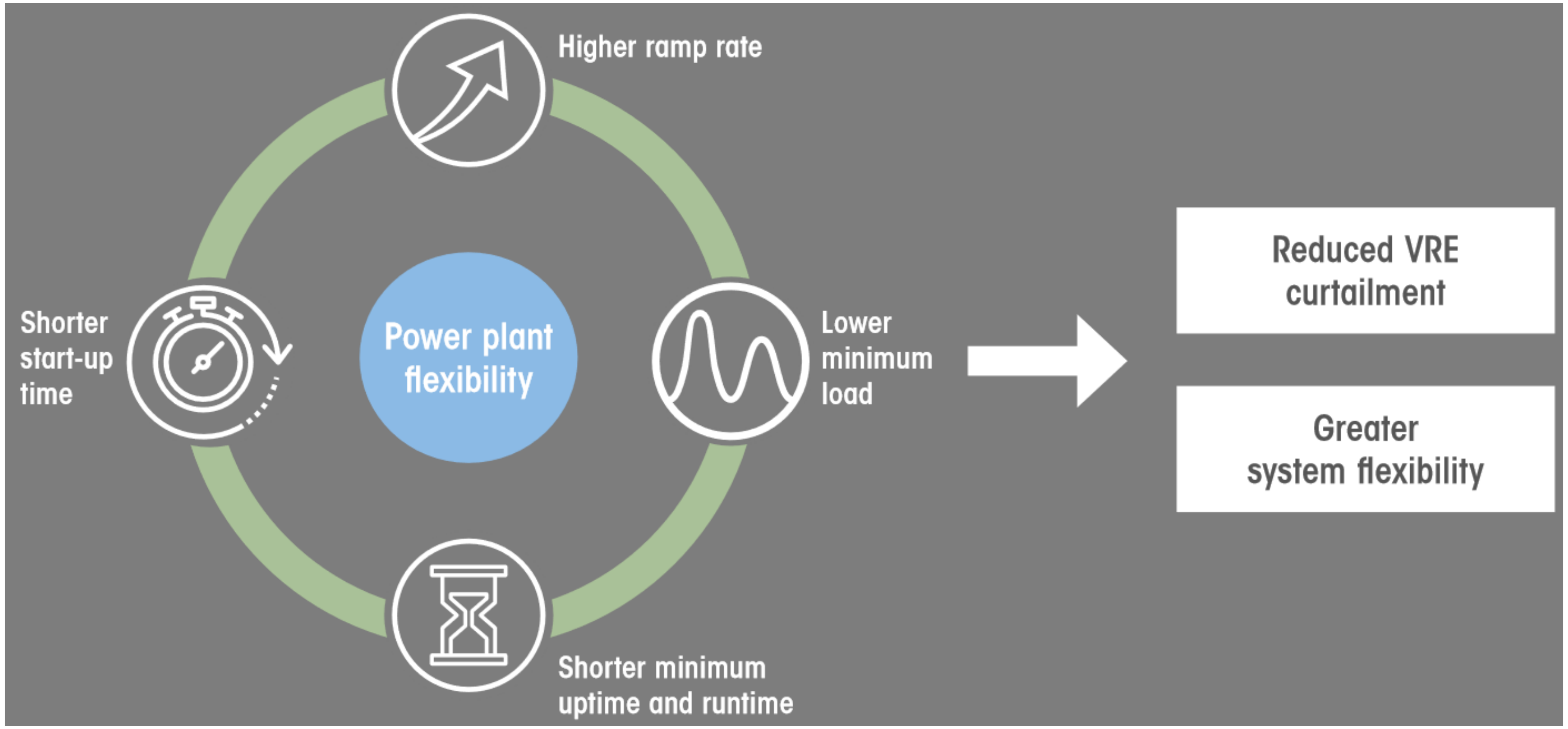
Ways to enable power plant flexibility:

✓Update market design to reward flexibility.

✓Adapt contracts for fuel supply and power provision.

✓Revamp standards, electricity grid codes, and market rules.

Figure. Components and benefits of conventional power plant flexibility



Source: IRENA (2019)

Case Studies: Flexible Thermal Generation

Denmark

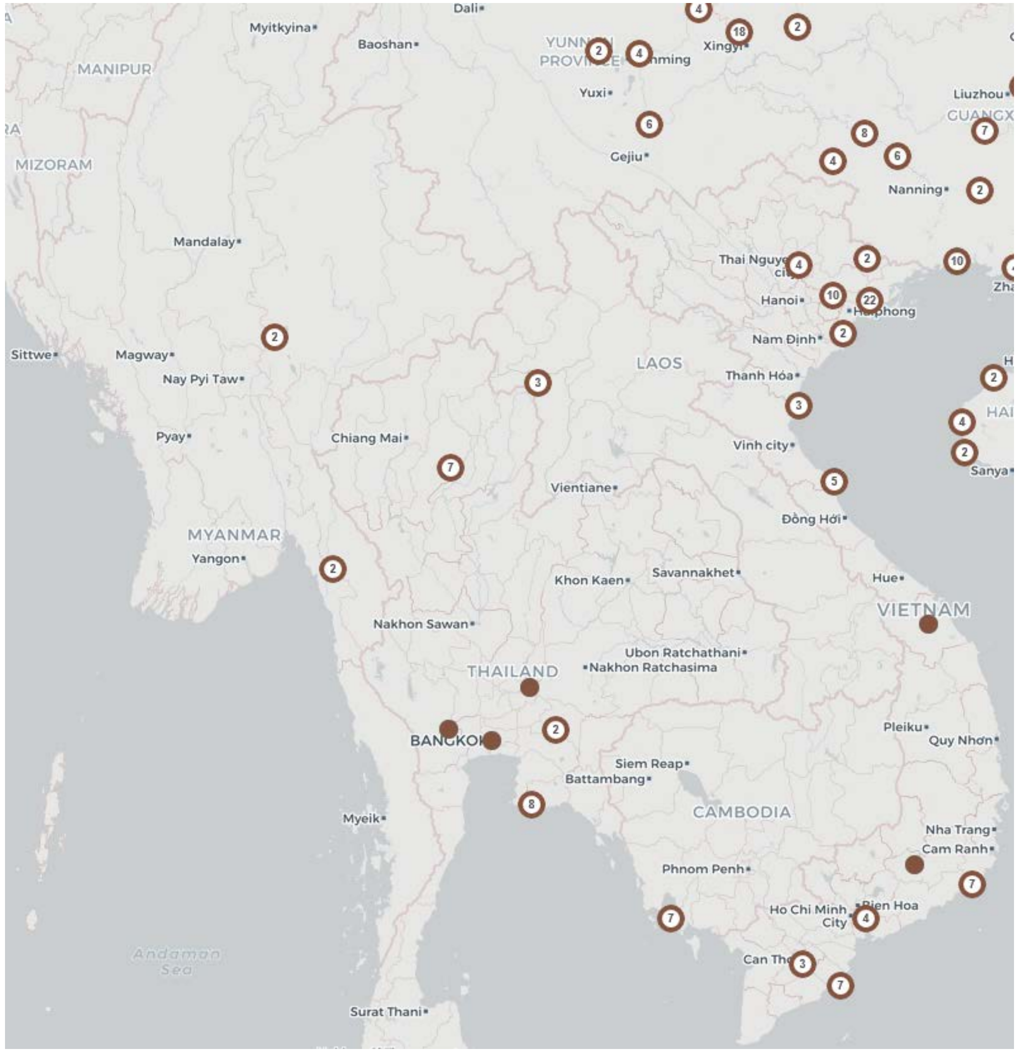
- Thermal plants designed and retrofitted explicitly for flexibility over the past decade to integrate VRE.
- Significant use of combined heat and power plants provide dispatchable generation and thermal storage.

Germany

- Changes at a coal power plant reduced the minimum load by 170 MW and increased the ramp rate by 10 MW/min.
- This involved upgrading the control systems, optimizing the software, and adjusting operations.

Source: IRENA (2019)

Figure. Operational coal plants in the Greater Mekong



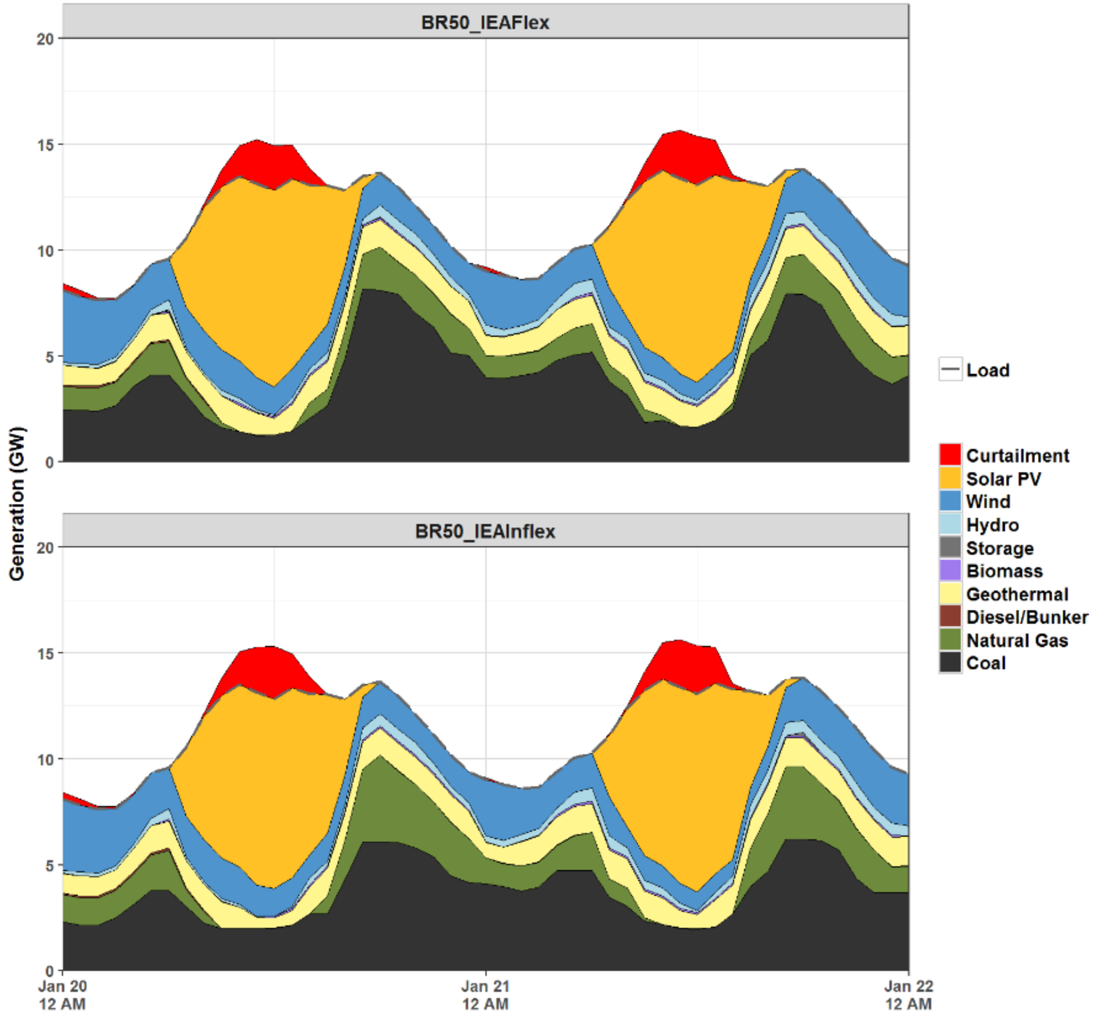
Source: Global Energy (GEM) Monitor Global Coal Plant Tracker (GCPT)

Case Study: Thermal Plant Cycling Costs

Philippines

- Grid Integration Study: what are the implications of higher amounts of RE (30% or 50%) in the Luzon-Visayas grid in 2030?
- Study contained a sensitivity to model conventional generator flexibility:
  - More flexible: Lower minimum stable level and shorter minimum downtime.
  - Less flexible: Higher minimum stable level and longer minimum downtime.
- Result: More flexible thermal generation resulted in higher annual wind and solar penetration, lower curtailment, and lower variable costs (negligible impact on emissions).

Figure. More flexible thermal plants (top) vs. less flexible thermal plants (bottom)



Source: Barrows et al. (2018)

Commitment and Dispatch Interval Reduction

Figure. Hourly dispatch

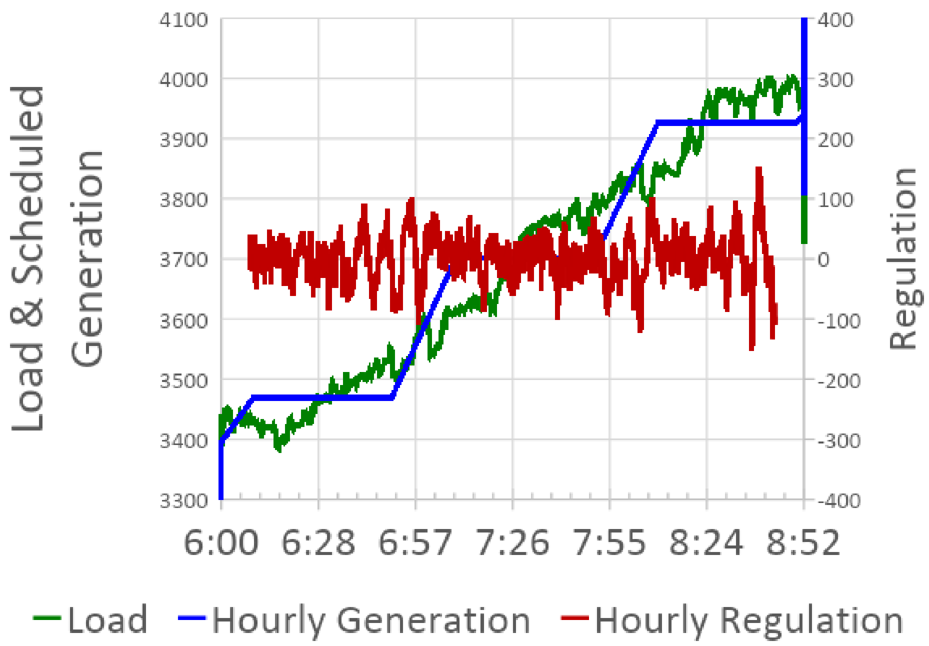
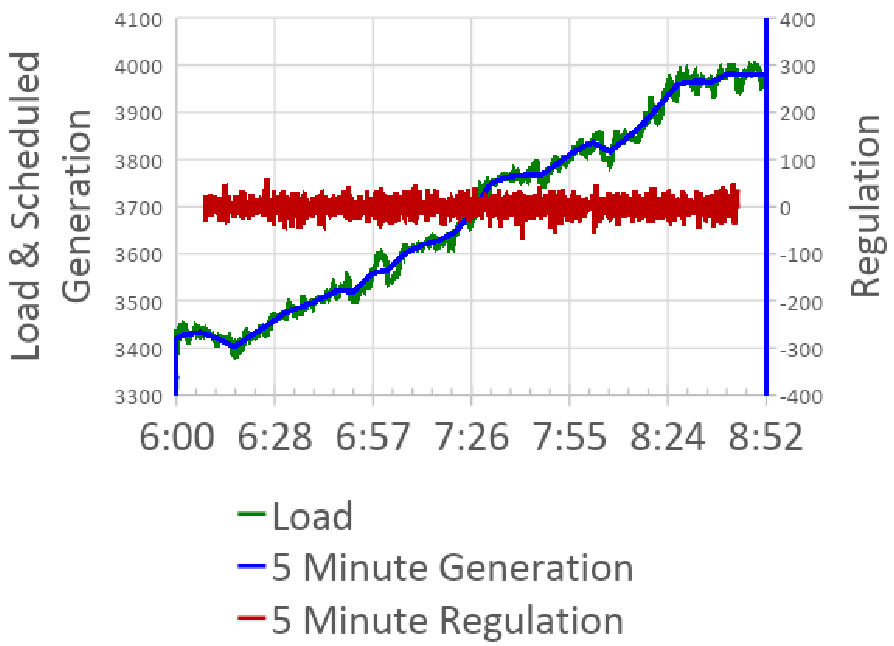


Figure. 5-minute dispatch



Dispatch interval: time increment used to dispatch generators to serve forecasted demand.

In the United States, 5-minute dispatch is predominantly a market mechanism; however, a market is not necessary.

Source: NREL

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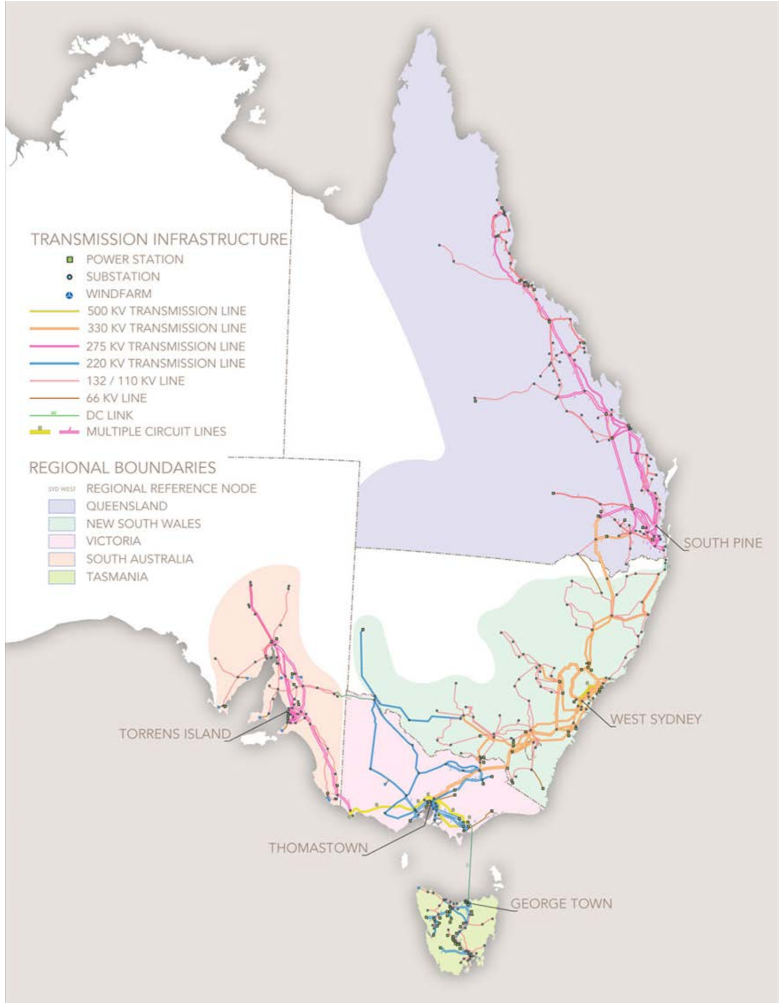
Case Study: Sub-Hourly Markets

Australia

- 5-minute dispatch period: generators bid to supply electricity for 5-minute block periods.
- 30-minute financial settlement period: generators were first paid based on the average prices over a 30-minute block.
- 2021: rule change decreases the financial settlement period to 5 minutes to align with the dispatch period, resulting in more efficient price signals and lower wholesale electricity costs.
- This 5-minute interval incentivizes flexibility and helps integrate Australia's significant amounts of distributed energy resources (DERs).

Source: IRENA (2019)

Figure. Regions of Australia's National Electricity Market (NEM)



Source: Australian Energy Market Operator (AEMO)

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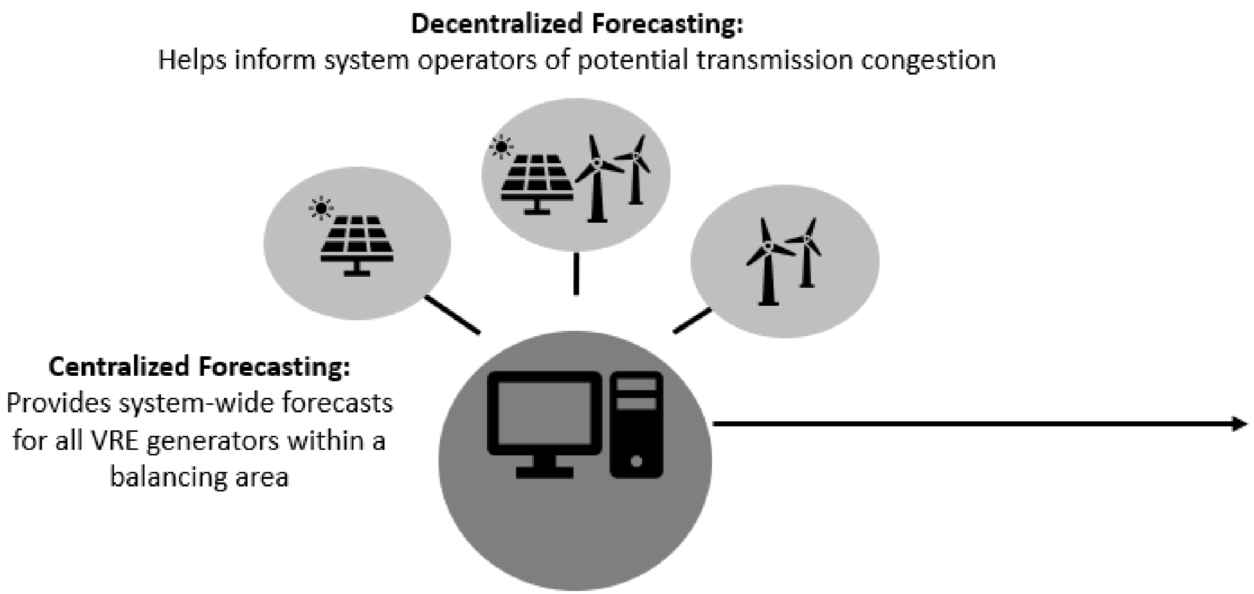
VRE Forecasting

Figure. VRE forecasting at different spatial and temporal resolutions helps integrate RE by anticipating energy production

Forecasting Spatial Resolution



Forecasting Temporal Resolution

	Type of Forecast	Time Horizon	Key Applications
Generation	Intra-hour	5-60 min	Regulation, real-time dispatch, market clearing
	Short term	1-6 hours ahead	Scheduling, load-following, congestion management
	Medium term	Day(s) ahead	Scheduling, reserve requirement, market trading, congestion management
	Long term	Week(s), Seasonal, 1 year or more ahead	Resource planning, contingency analysis, maintenance planning, operation management

Source: Joshi and Logan (2022)

Demand Response

Demand Response (DR): “changes in utility-supplied electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity during a day and/or season, or to other economic compensation designed to induce change in the use of utility-supplied electricity, to provide a resource option for electric system planners and operators in balancing supply and demand”

Peak Shaving
DR can reduce peak load or net peak load in grids w/ high variable renewable energy (VRE) penetration by curtailing certain end-uses. This could reduce the required generation capacity that needs to be built.

Flexible Loads
DR can shift flexible loads from peak to off-peak hours to better align demand with supply. This could reduce VRE curtailment and the ramping requirements of thermal generators.

Emergency Shedding
DR can enable targeted load shedding when grid is highly stressed (e.g., large industrial customers shift to backup generation during contingency events like severe weather or unplanned generator outages).

End-Uses
The following end-uses can be involved in DR programs: smart appliances, water heaters, residential/commercial thermostats, air conditioning, pool pumps, behind-the-meter generation w/ storage, electric vehicles (EVs), etc.

Programs
Participants in a DR program receive payments from utilities or DR aggregators when electricity consumption is curtailed or respond to time-of-use pricing to shift consumption to lower-cost periods.

Source: Elsworth et al. (2022)

Summary: Solutions for Managing VRE

- Integration must consider both physical and institutional changes to the system for better complementing VRE.

- There are many flexibility options that are cheaper than storage. Some options are institutional and require change of protocol or policy (often, institutional changes are the most cost-effective).

- The three primary VRE integration measures:
  - Increase the geographic diversity of wind and solar plants.
  - Enact a shorter interval for generator commitment and dispatch.
  - Integrate weather-based power generation forecasting.

- Demand-side resources (including electric vehicle behavior) using appropriate compensation should be considered for contributing to supply/demand balance.

- The Greater Mekong’s goals can be supported by moving down the RE integration path.

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RE Data Explorer Overview

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Figure. Potential use-cases for high-quality RE data

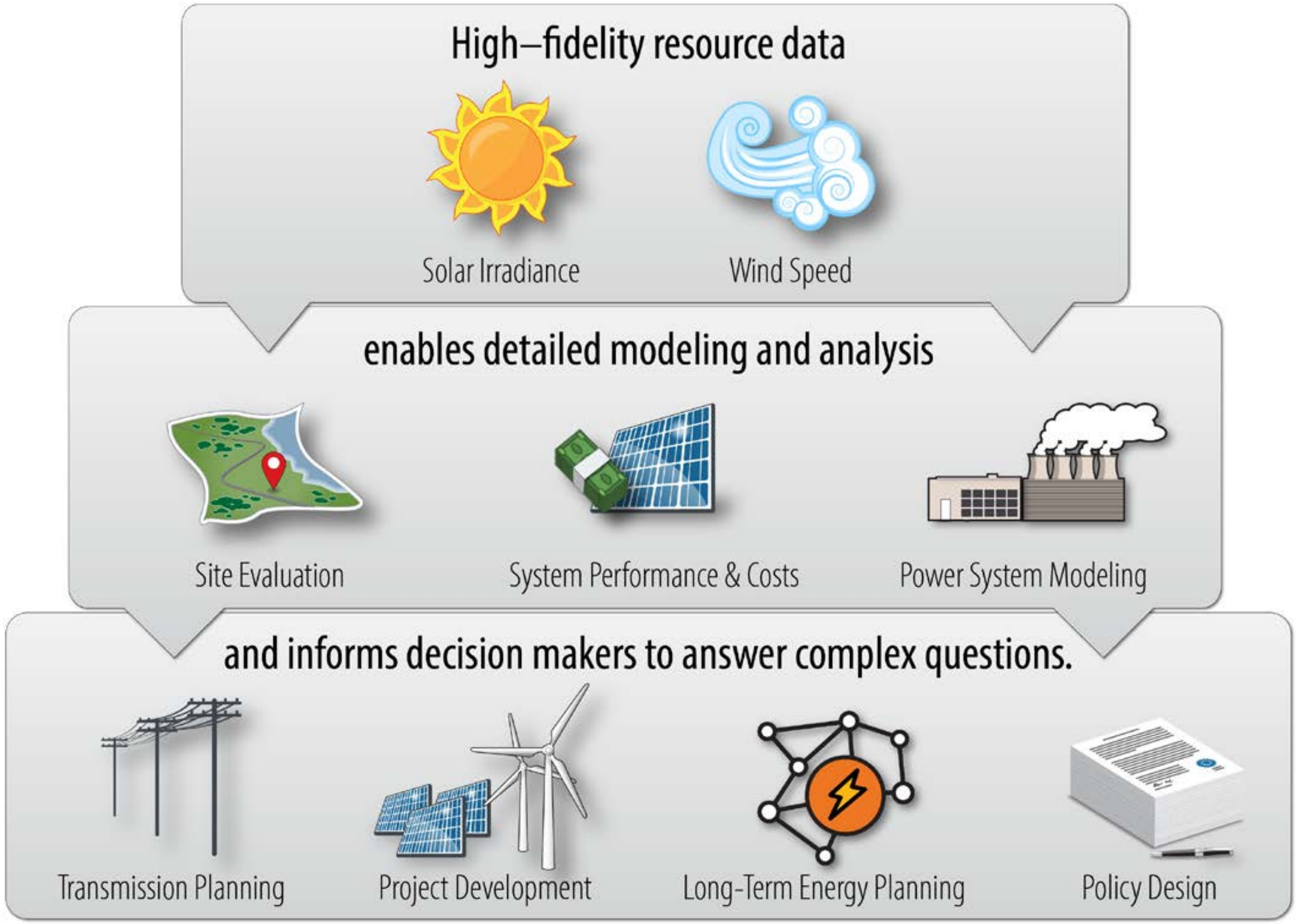

Image: Billy Roberts (NREL)

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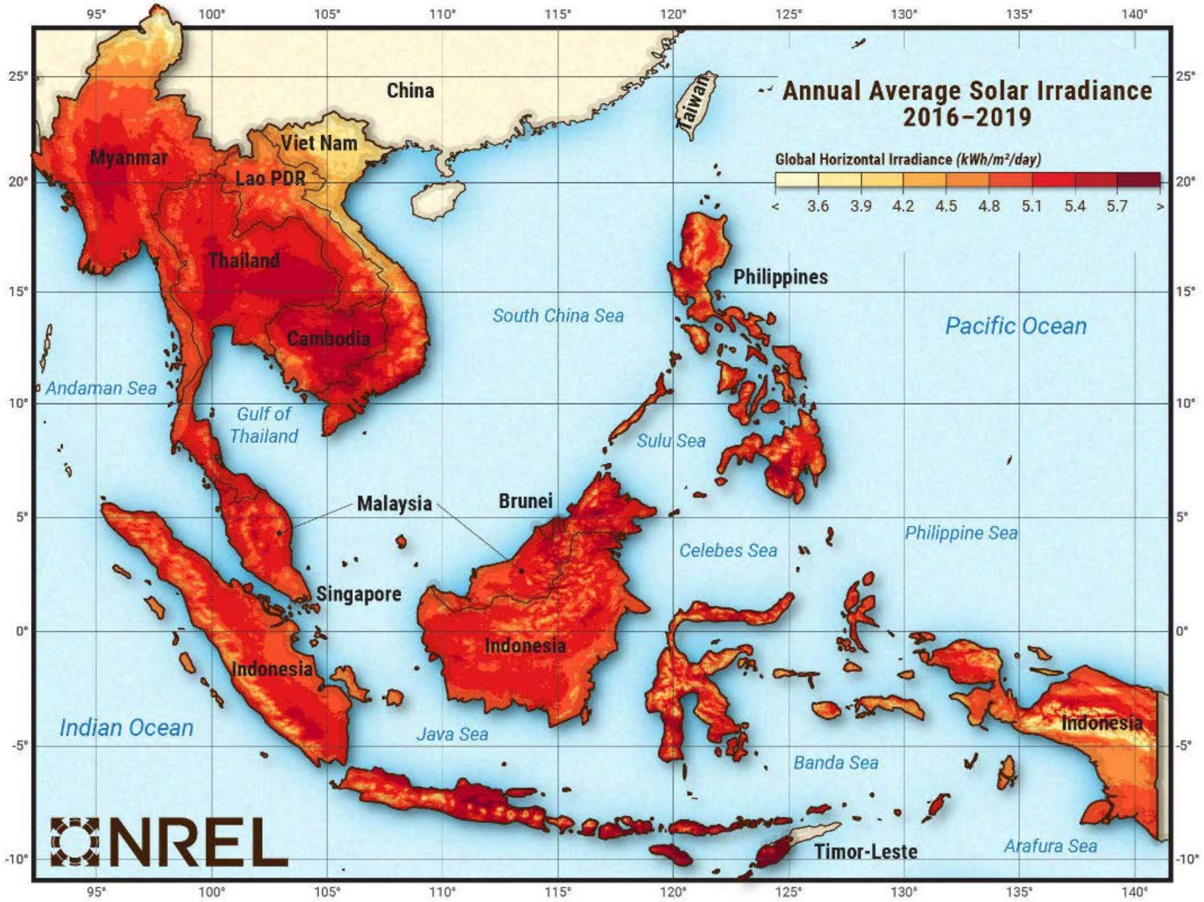
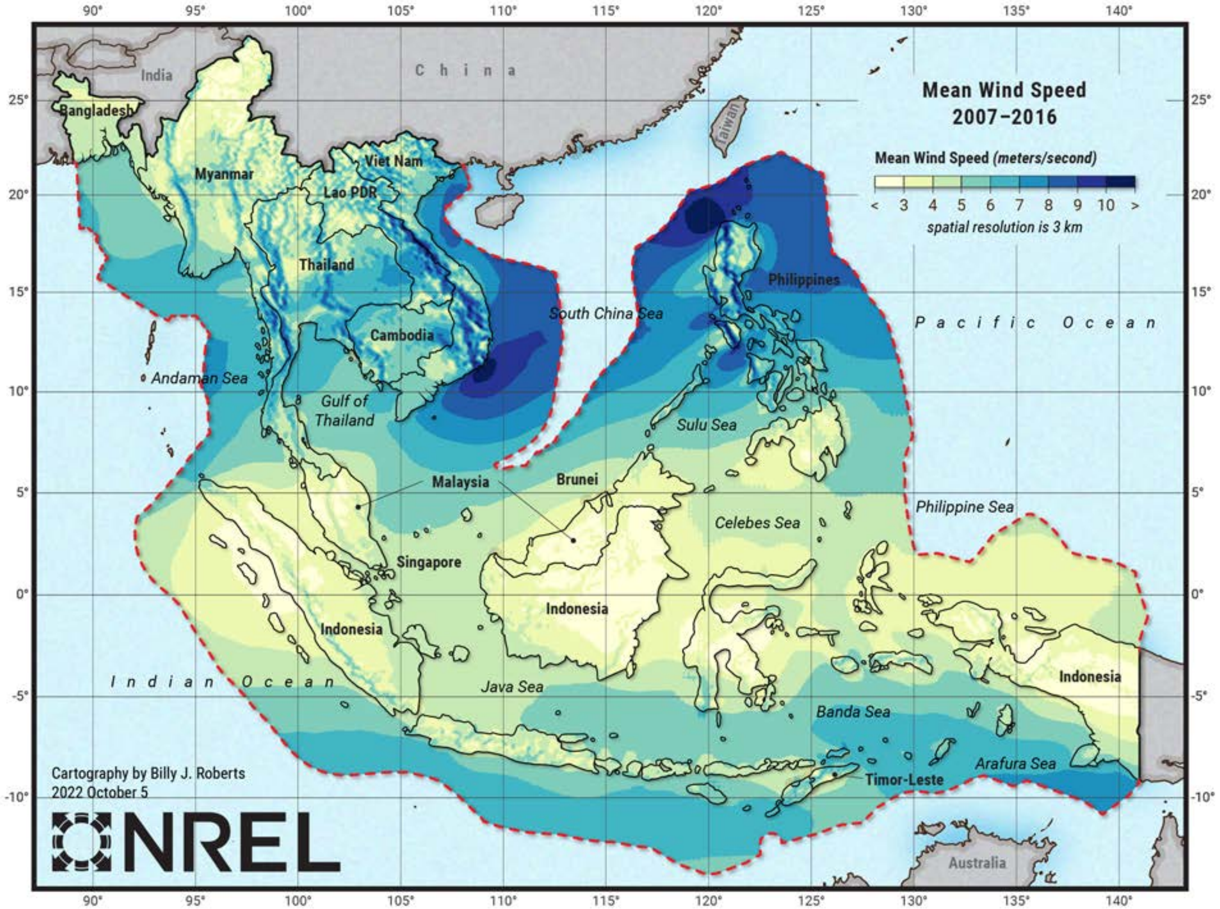
Southeast Asia Wind and Solar Data

Figure. Southeast Asia solar resource data



Spatial Resolution: 2-km x 2-km
Temporal Resolution: 10 minutes

Figure. Southeast Asia wind resource data



Spatial Resolution: 3-km x 3-km
Temporal Resolution: 15 minutes

Images: Billy Roberts (NREL)

Source: Maclaurin et al. (2022)

Section 2:
Select VRE Integration Solution Deep Dives

Energy Storage Fundamentals

Floating Solar Fundamentals

Cross-Border Energy Trade Fundamentals

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Trends

Market

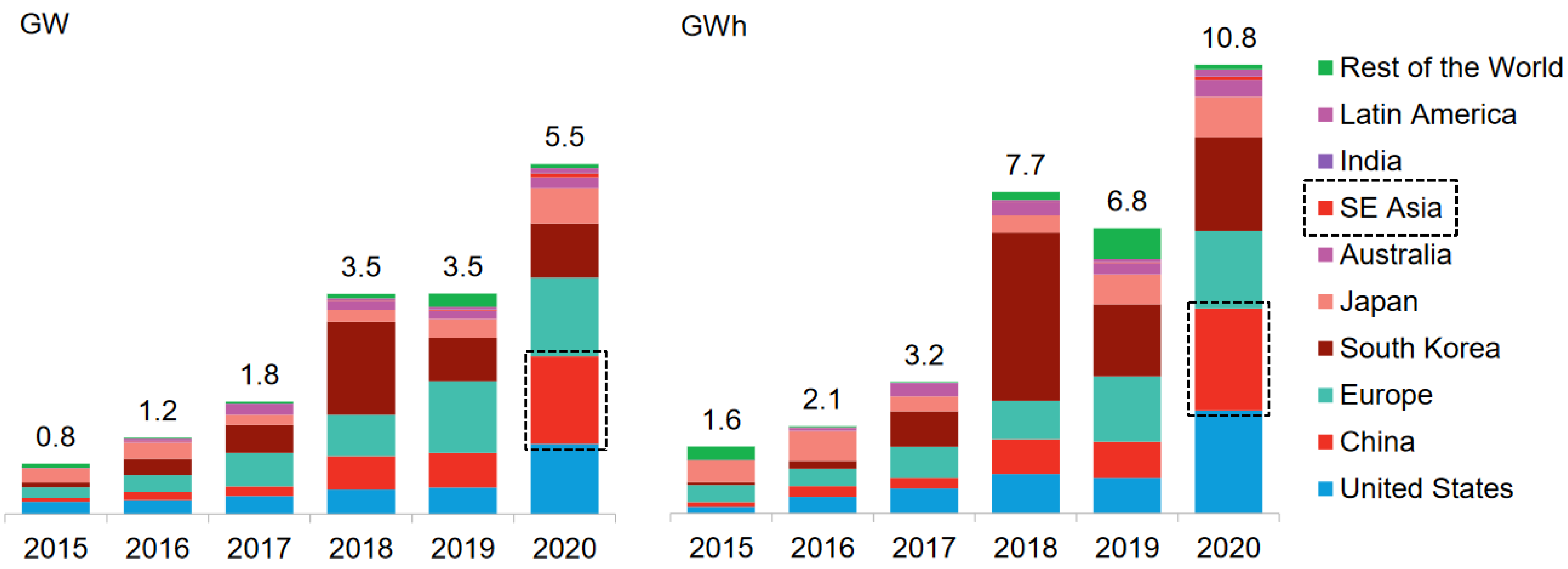

Figure. Global energy storage build by market, 2015-2020

Source: Bloomberg New Energy Finance (2022)

Projections

Market

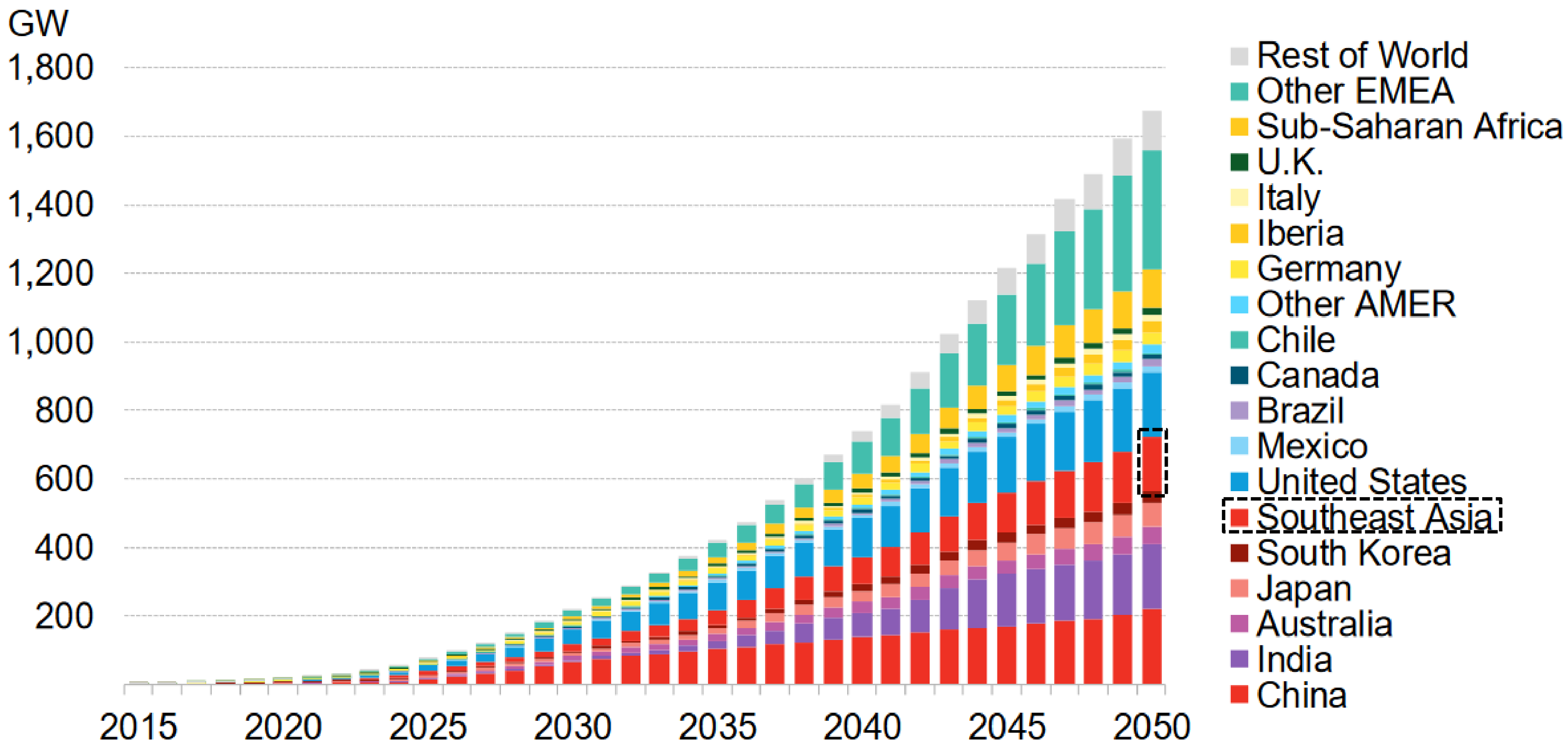

Figure. Global energy storage projection by market, 2015-2020

Source: Bloomberg New Energy Finance (2022)

SE Asia energy storage market is expected to reach USD 4.24 billion by 2027, registering a compound annual growth rate of 6.78% during the forecast period of 2022-2027.

Source: Mordor Intelligence (2023)

Cost Reductions

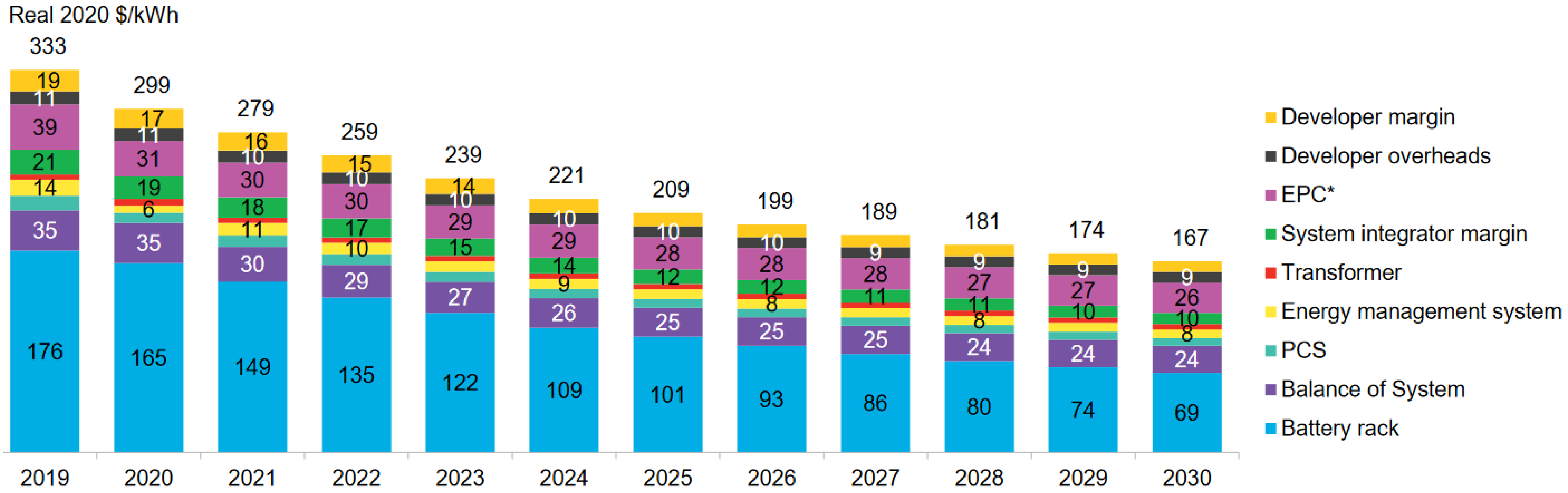

Figure. Stationary storage system (4-hour AC battery energy storage system) cost trend and projection, 2019-2030

Source: Bloomberg New Energy Finance (2022)

Storage Technology Overview

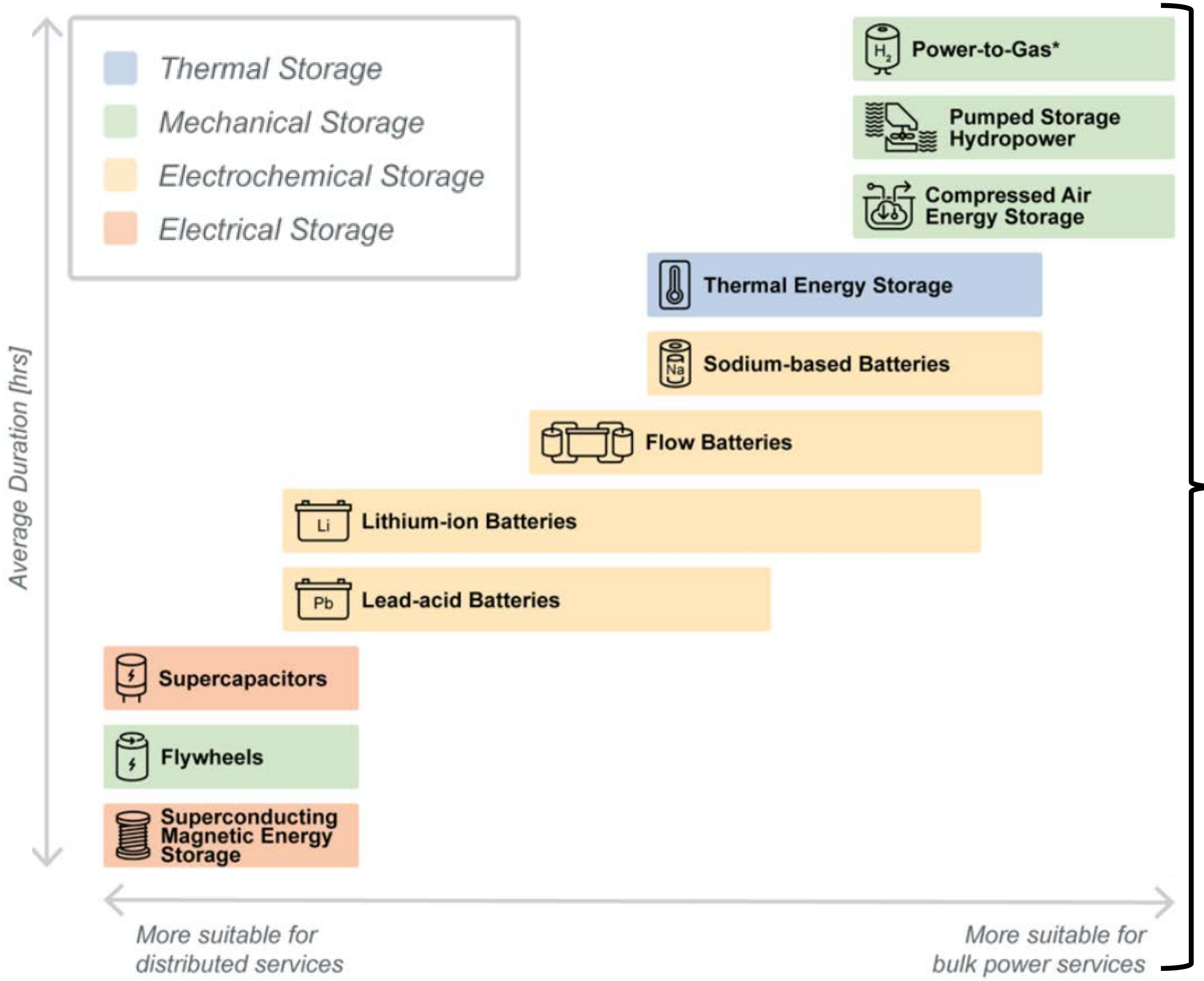

Figure. Ecosystem of energy storage technologies and services

Source: Bowen et al. (2021)

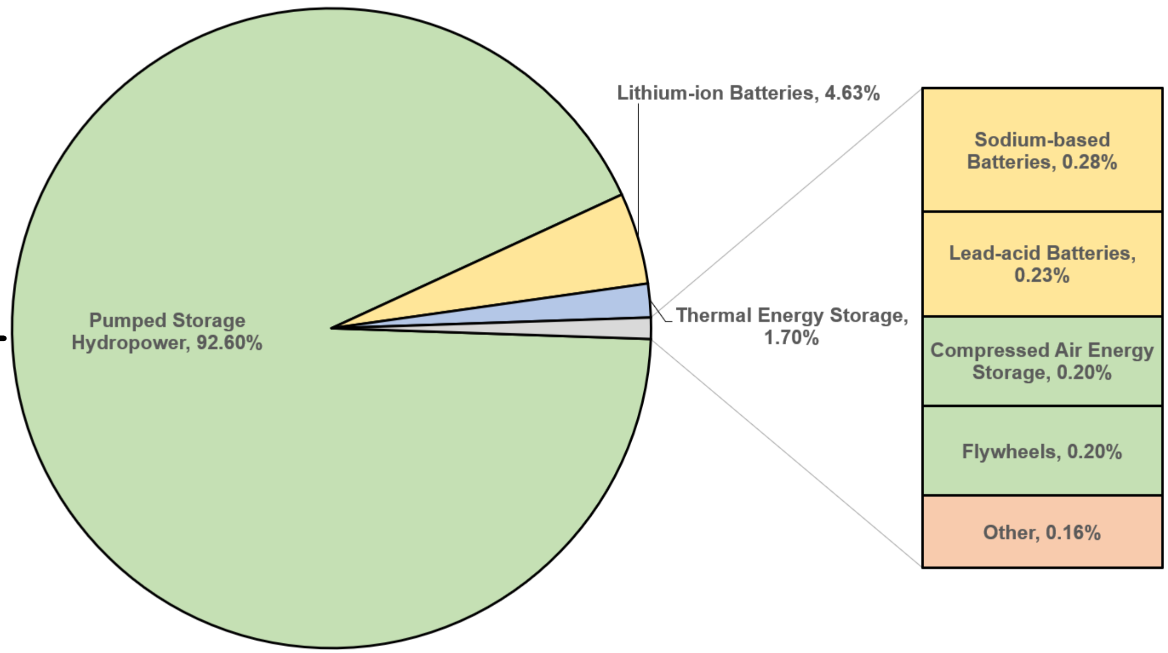

Figure. Global total operational energy storage project capacity, 2020

Source: Joshi and Gokhale-Welch (2022)

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Pumped Storage Hydropower (PSH)

Figure. PSH configurations

Open-Loop PSH	**Closed-Loop PSH**
Projects are continuously connected to a naturally flowing water feature.	Projects are not continuously connected to a naturally flowing water feature.

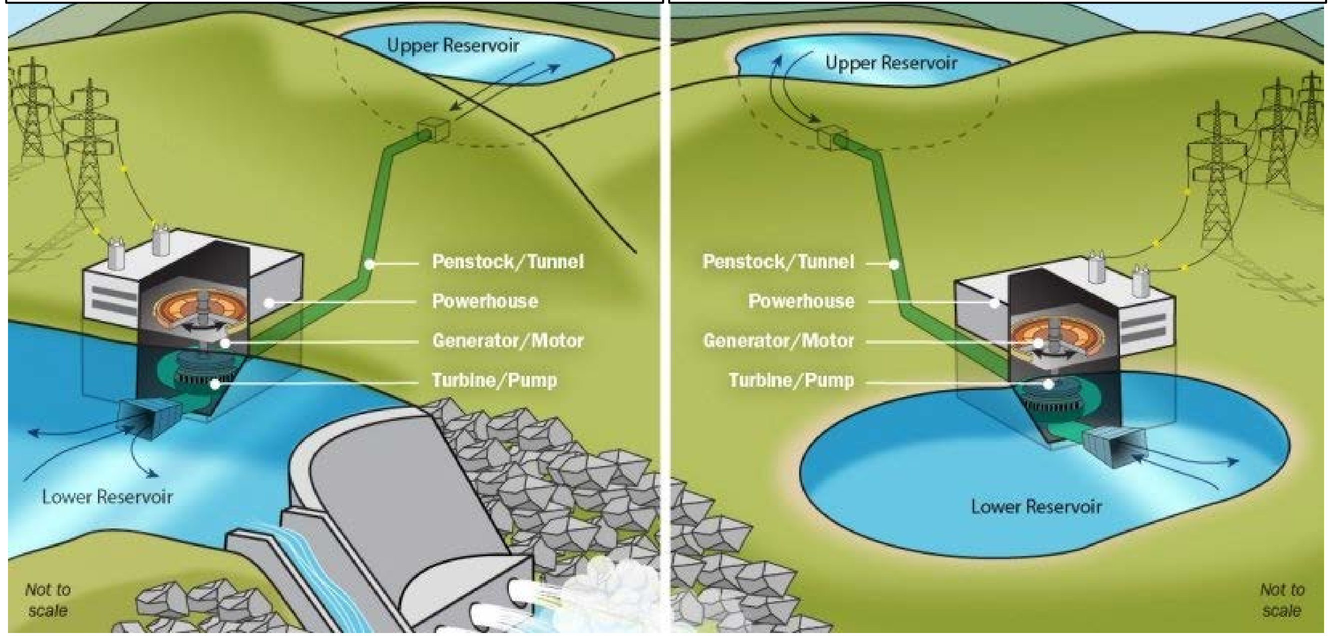

Image: U.S. Department of Energy (2023)

Advantages

- Most developed and widely commercialized energy storage technology in the power sector.
- Large capacities and long durations make it well suited to provide a variety of grid services.

Challenges

- Limited by geographic requirements.
- High capital costs.

Source: Bowen et al. (2021)

560 MW of PSH capacity in Thailand as of 2021.

Data: IRENA (2022)

Power-To-Gas: Hydrogen

Method	Status	Feedstock
Gasification	Mature	Coal or biomass
Steam (Methane) Reforming	Mature	Natural gas or biogas
Electrolysis		
Proton-Exchange Membrane	Pilot for at-scale production	Electricity plus water
Alkaline	Mature at scale	
Solid Oxide	R&D	

Figure. Select methods for producing hydrogen

Source and Image: Bowen et al. (2021); Denholm et al. (2021)

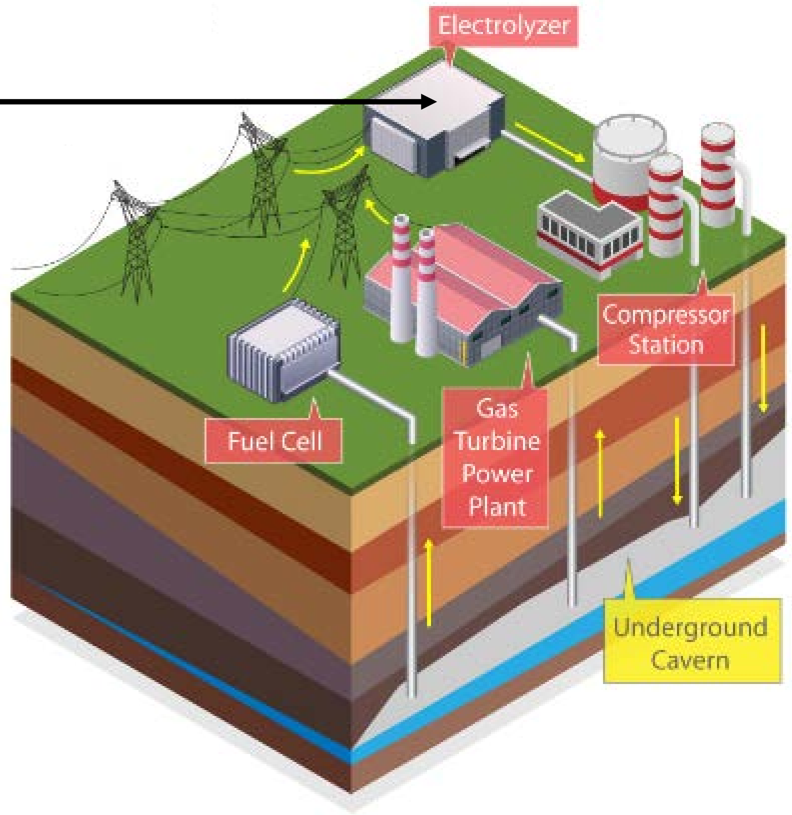

Figure. Schematic of hydrogen production via electrolysis, storage, and use in fuel cells or turbines

Advantages

- Potential to provide seasonal long-duration storage.
- Applications for hydrogen in transportation and industry.

Challenges

- Costs of electrolysis and subsequent power generation are currently high.
- Significant support infrastructure required.

Thailand is piloting green hydrogen and fuel cells for power; Vietnam is exploring the feasibility of co-firing ammonia in coal power plants.

Source: IEA (2022)

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Thermal Energy Storage (TES)

Sensible heat storage

- Uses temperature changes within a solid or liquid medium to store thermal energy.

Latent heat storage

- Phase change materials that absorb and release thermal energy through melting and freezing.

Thermochemical storage

- Releases or stores thermal energy as a byproduct of chemical reactions.

Source: Bowen et al. (2021)

Images: Prateek Joshi (NREL); Dennis Schroeder (NREL)

Applications of TES

Figure. Pumps for district heating system

- TES decouples electricity supply from heat supply in district heating systems, enabling flexibility.

Figure. Concentrating solar-thermal power plant

- TES allows electricity production from concentrated solar power plants even when sunlight is not available.

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Electrochemical Battery Storage

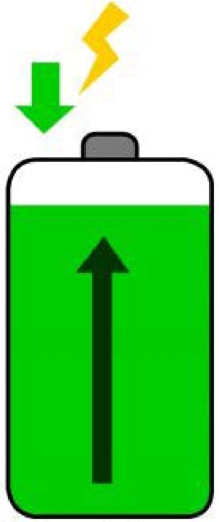
	Advantages	**Disadvantages**
Lithium-Ion	• Relatively high energy and power density • Lower maintenance costs • Rapid charge capability • Many chemistries offer design flexibility • Established technology with strong potential for project bankability.	• High upfront cost ($/kWh) relative to lead-acid (potentially offset by longer lifetimes) • Poor high-temperature performance • Safety considerations, which can increase costs to mitigate • Currently complex to recycle • Reliance on scarce materials.
Flow (Vanadium-Redox)	• Long cycle life • High intrinsic safety • Capable of deep discharges.	• Relatively low energy and power density.
Lead-Acid	• Low cost • Many different available sizes and designs • High recyclability.	• Limited energy density • Relatively short cycle life • Cannot be kept in a discharged state for long without permanent impact on performance • Deep cycling can impact cycle life • Poor performance in high temperature environments. • Toxicity of components
Sodium-Sulfur	• Relatively high energy density • Relatively long cycle life • Low self-discharge.	• High operating temperature necessary • High costs.

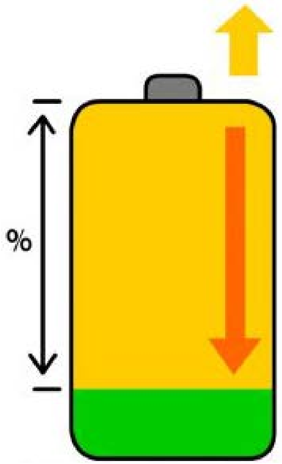
Source: Bowen et al. (2021)

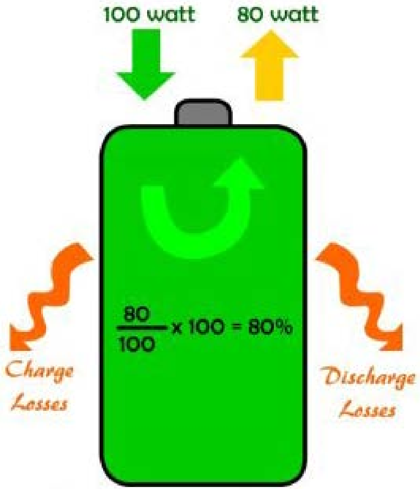
Attributes

Energy storage projects are rated based on **power** (MW/kW) and **energy** (MWh/kWh).

Figure. Other attributes of battery storage systems







State of Charge

The percentage of battery energy capacity still available in the battery.

Depth of Discharge

The percentage of the battery that has been discharged relative to the total battery energy capacity.

Round-Trip Efficiency

The ratio of the energy recovered from the battery to the energy input into the battery. Losses include heat loss.

Source: Joshi and Gokhale-Welch (2022)

Distributed Battery Storage for Resilience

When coupled with a renewable distributed energy generation source (e.g., solar PV), battery storage can provide backup generation for extended periods of time (days to weeks):

- Decreases the size of other backup generation (e.g., diesel generators) and extends limited fuel supply
- Is a fully renewable backup power source (when coupled with renewables) that does not need refueling
- Can provide revenue streams while grid connected (e.g., demand charge reduction, demand response programs, energy arbitrage, etc.).

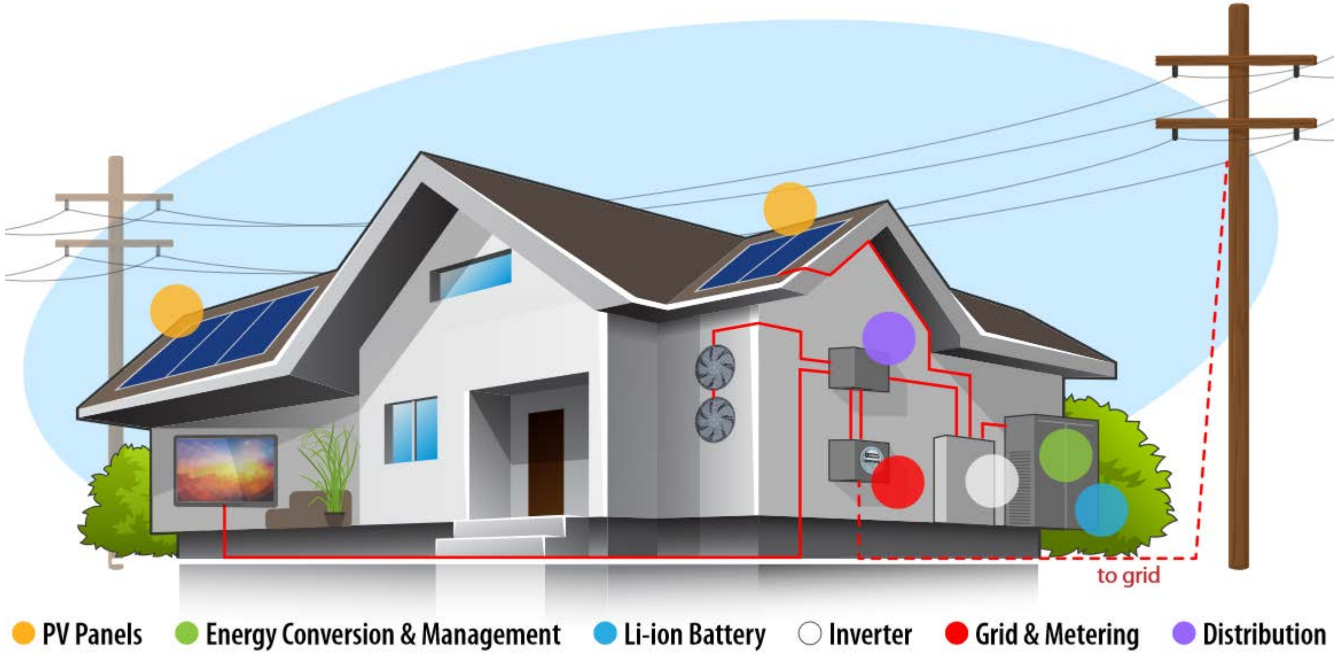


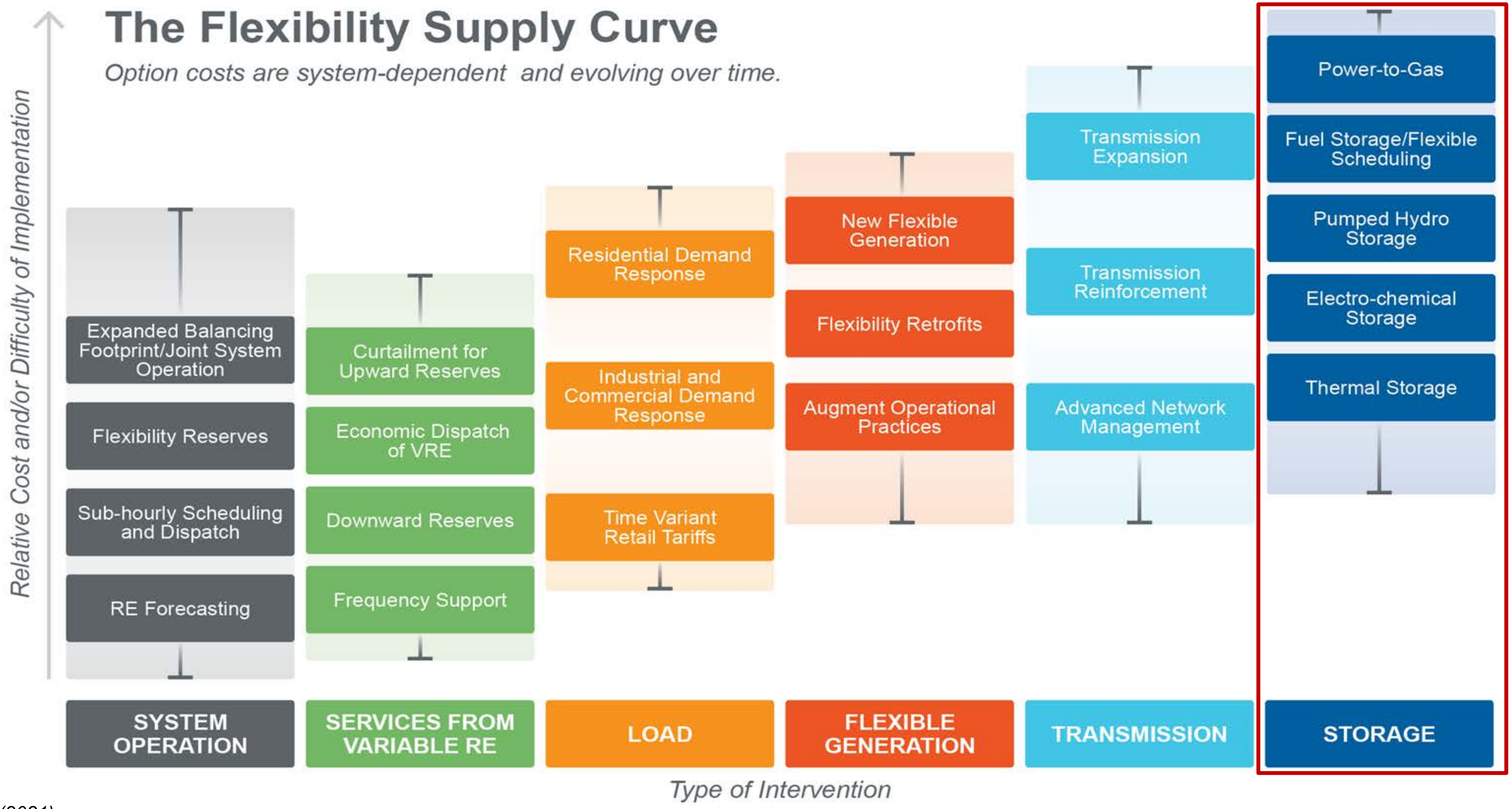
Figure. Illustration of residential solar PV and distributed battery storage system

Image: Alfred Hicks (NREL)

Source: Joshi and Gokhale-Welch (2022)

Storage Can Help Integrate Renewables

Figure. Different options to increase grid flexibility and integrate VRE



Source: Chernyakhovskiy et al. (2021)

Storage Can Provide Variety of Grid Services

Figure. Services that storage can provide for generation, transmission, and distribution

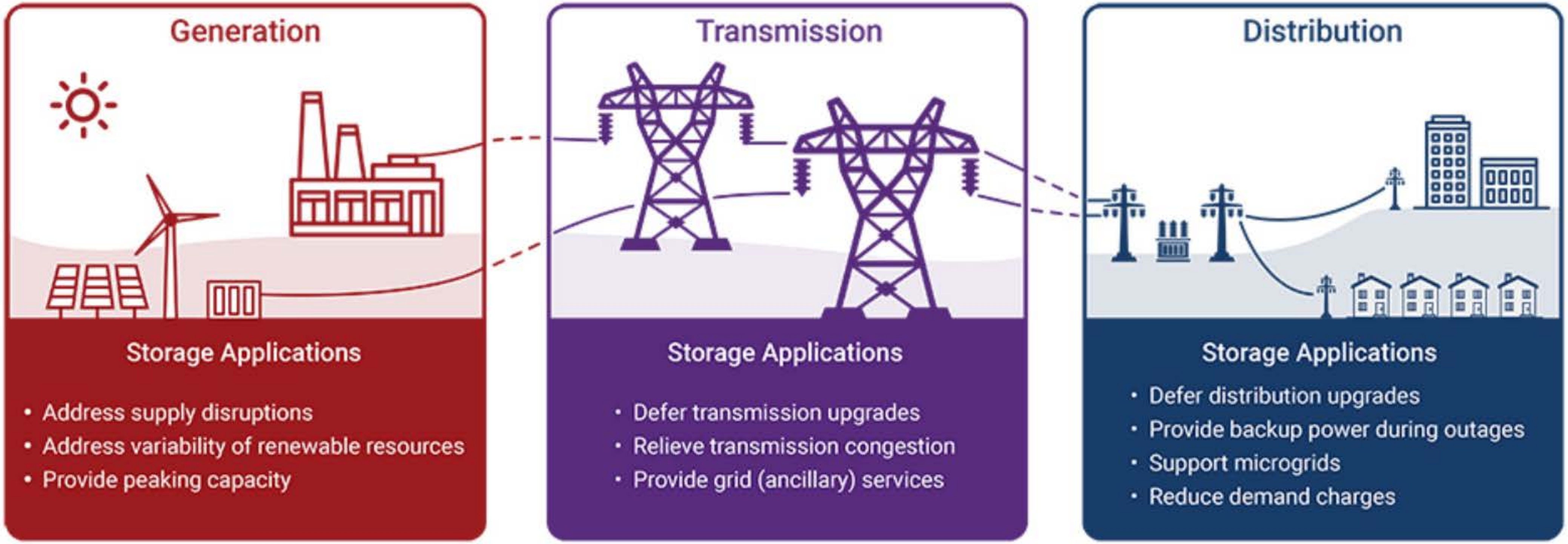


Image: Clear Path (2018)

Section 2:
Select VRE Integration Solution Deep Dives

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Floating Solar Fundamentals

Cross-Border Energy Trade Fundamentals

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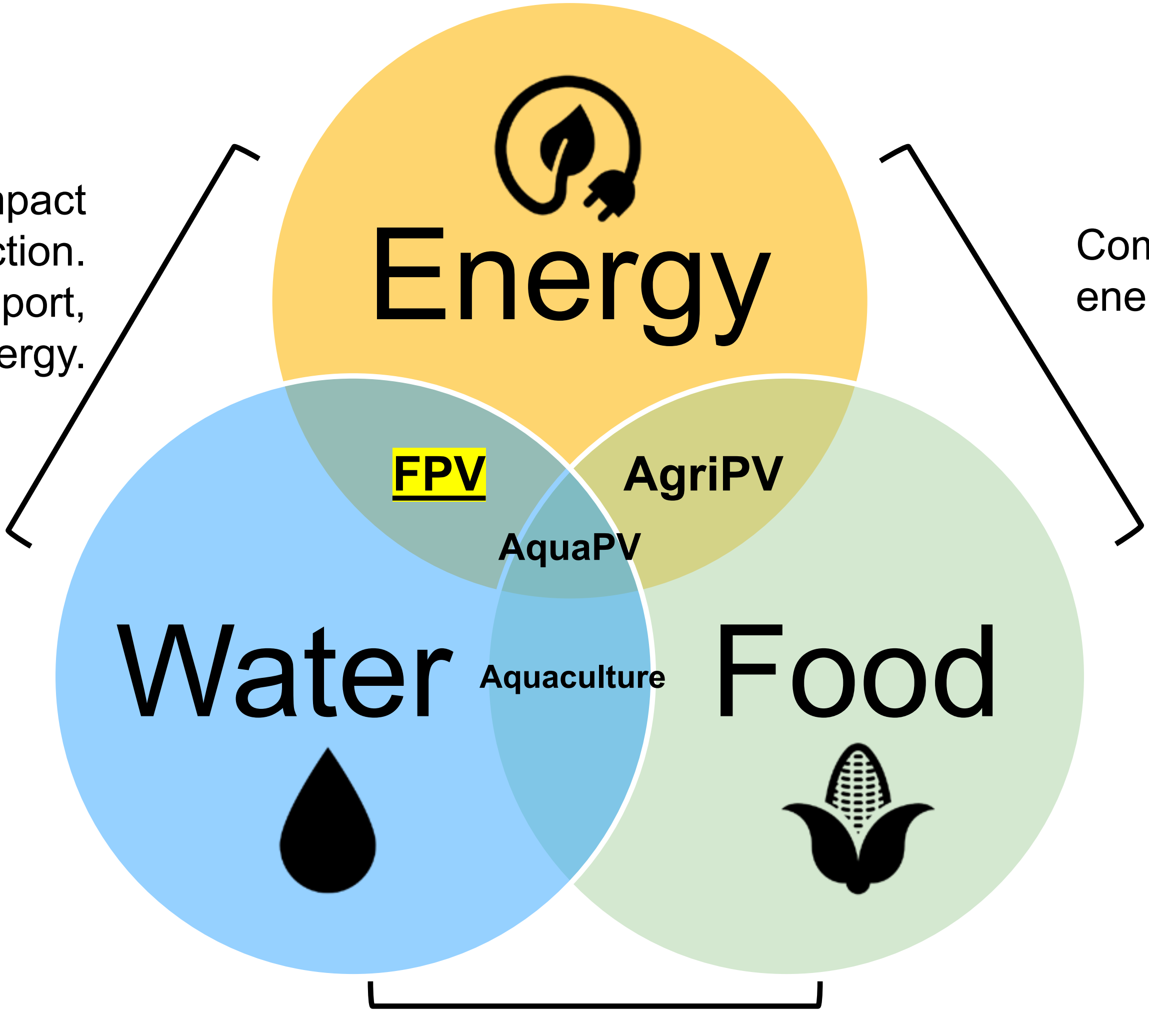
Image: iStock

Food-Energy-Water Nexus

Limited water resources can impact energy production.
Water infrastructure (transport, treatment, etc.) requires energy.



Competing land use for food and energy production.

Figure. The Food-Energy-Water nexus and FPV system interactions

Land development impacts water quality and availability.
Water shortages and poor water quality limit food production.

Source: Joshi (2023)

Technology Overview: Floating Solar PV

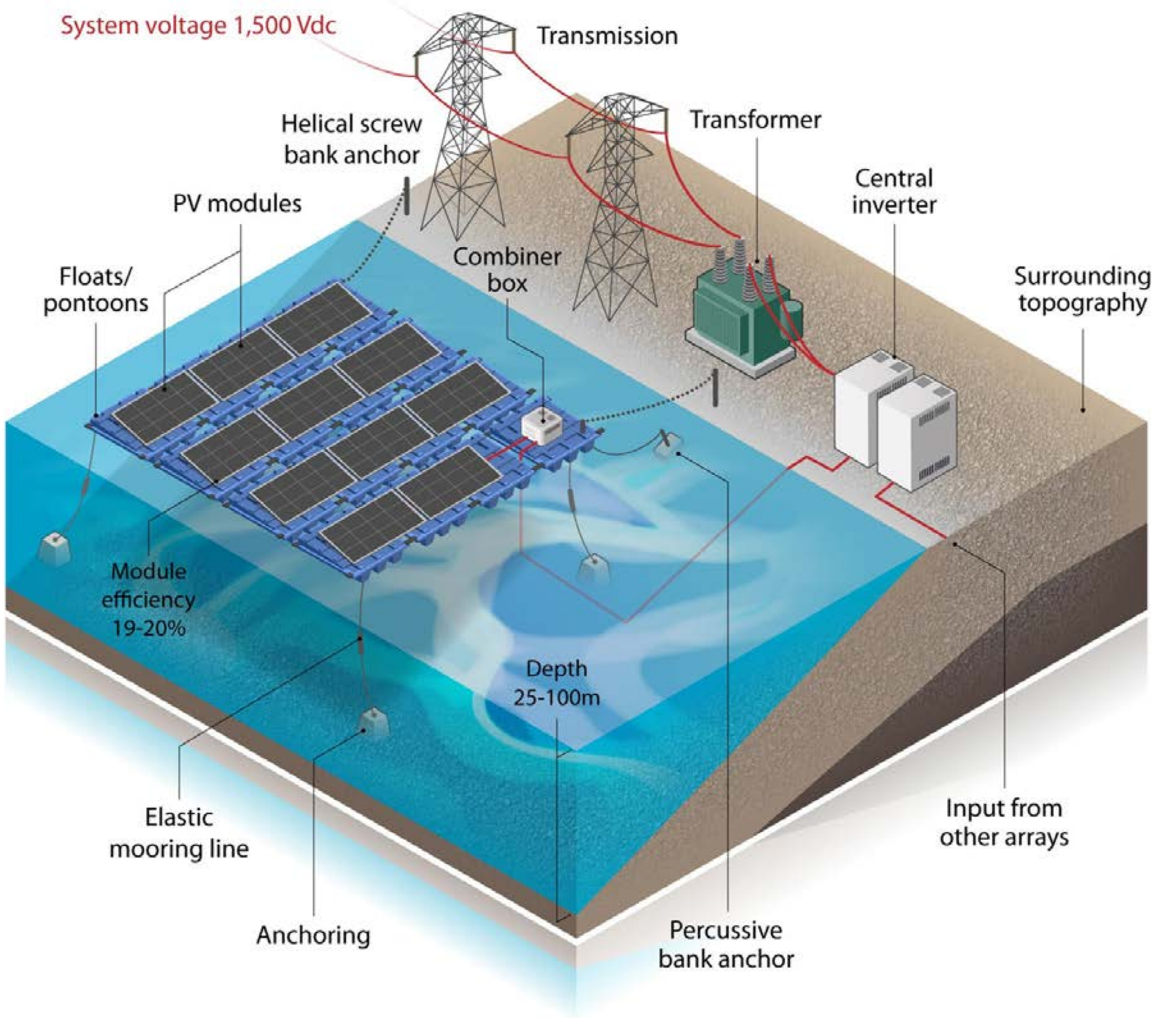


Figure. Schematic of typical FPV system

Image: Alfred Hicks (NREL)

- ❖ Uses the same PV modules as ground-mount or rooftop PV.
- ❖ Historically has been sited on artificial waterbodies (e.g., reservoirs, retention ponds, etc.).
- ❖ Floating solar PV (FPV) systems are mounted on floating platforms constructed with plastic and stainless steel.
- ❖ These platforms are linked and then connected to mooring lines that are anchored to the shore, bottom of the water body, or floating anchors.
- ❖ The system is connected to the main electrical equipment, which generally resides onshore, and the grid through underwater cables.

Source: Ramasamy and Margolis (2021)

FPV vs. Ground-Mount PV Costs

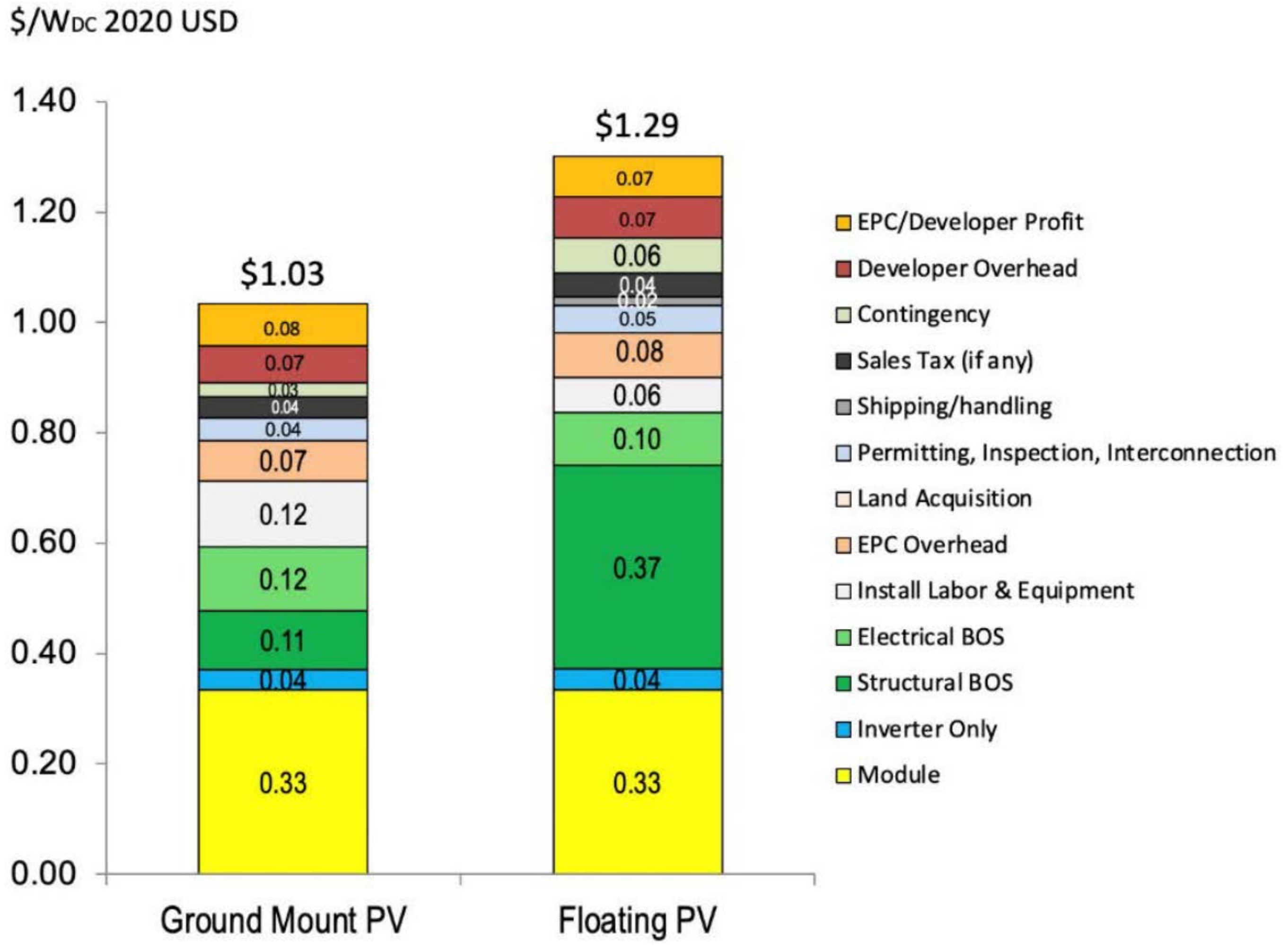


Figure. U.S. installed costs of 10-MW DC FPV and ground-mount PV systems

Source: Ramasamy and Margolis (2021)

- Modeled FPV system has a higher installed cost, $0.26/WDC (25%) greater than the cost per watt DC of ground-mounted PV.
- Largely due to higher structural costs related to the floats and anchoring system.

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FPV Benefits

	Social	Economic	Energy	Water	Food/Land
Empirically Confirmed	• Reduces land use (S) • Repurposes otherwise unusable land (S)	• Increases ease of installation (S,H) • Reduces site preparation (S,H) • Modular (S,H)	• Increases panel efficiency (S) • Increases panel packing density (S,H) • Reduces shading (S,H)		• Reduces land use (S) • Repurposes otherwise unusable land (S)
Theoretically Confirmed	• Preserves valuable land and water for other uses (S,H)	• Uses existing electrical transmission infrastructure • Reduces curtailment • Improves power quality	• Increases panel efficiency (H) • Improves power quality (H)	• Reduces evaporation (S,H) • Reduces algae growth/ Improves water quality (S)	• Increases energy sources near demand/ population centers (S,H)
Unclear, Unconfirmed, or Understudied	•Avoids or reduces conflicts over land and water use (S,H) • Reduces or avoids power-generation related air pollution (S,H) • Reduces displacement of local communities for energy development (S,H) • Improves power sector resilience (S,H)	• Extends system life (S,H)		• Reduces algae growth/ Improves water quality (H) • Reduces water temperature (S,H) • Provides power during drought • Reduces wave formation (S,H)	

Social and water-related co-benefits remain understudied.

Figure. Summary of FPV co-benefits (S = stand-alone, H = hybridized)

Source: Gadzanku et al. (2021)

Case Study: What are the operational benefits of hybridizing FPV with hydropower?

Canada and Brazil, like the Greater Mekong Subregion, also rely on hydropower for significant shares of electricity generation.

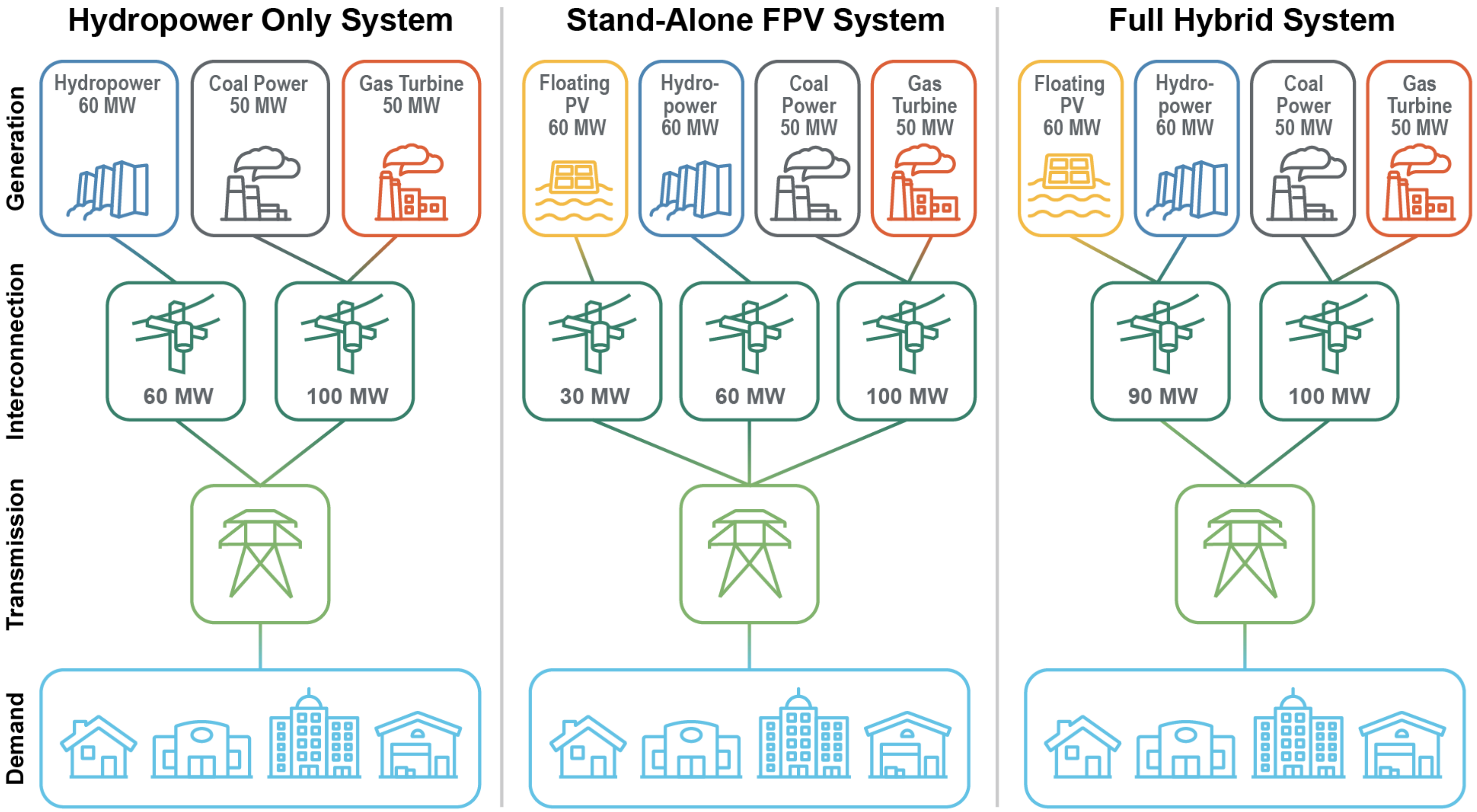

Figure. Example system configurations for the hydro-only (left), FPV stand-alone (middle), and hybrid FPV-hydropower (right) systems

Source: Gadzanku (2022)

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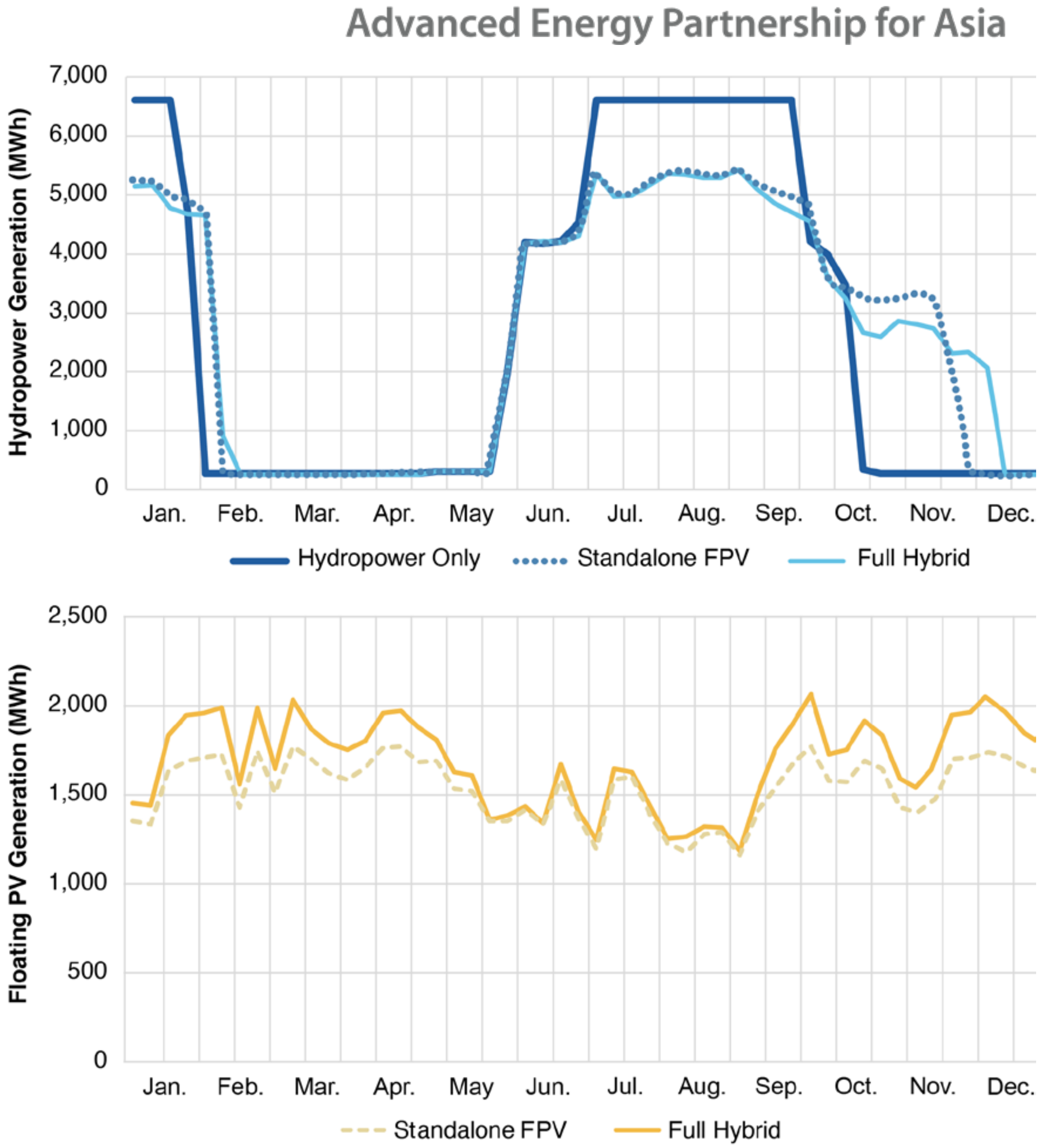
What were some of our findings?

Compared to a stand-alone FPV system, hybridizing FPV with hydropower helps:

- Lower PV curtailment when transmission constraints cause curtailment.
- Reduce dependence on other types of generation, such as gas-fired generation, by reducing PV curtailment.
- Conserve water by shifting hydropower generation to other periods of the year.

Figure. Results showing shifted hydropower generation (top) and increased PV production (bottom) of modeled hybrid hydropower-FPV systems



Source: Gadzanku et al. (2022)

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Potential in Southeast Asia: FPV

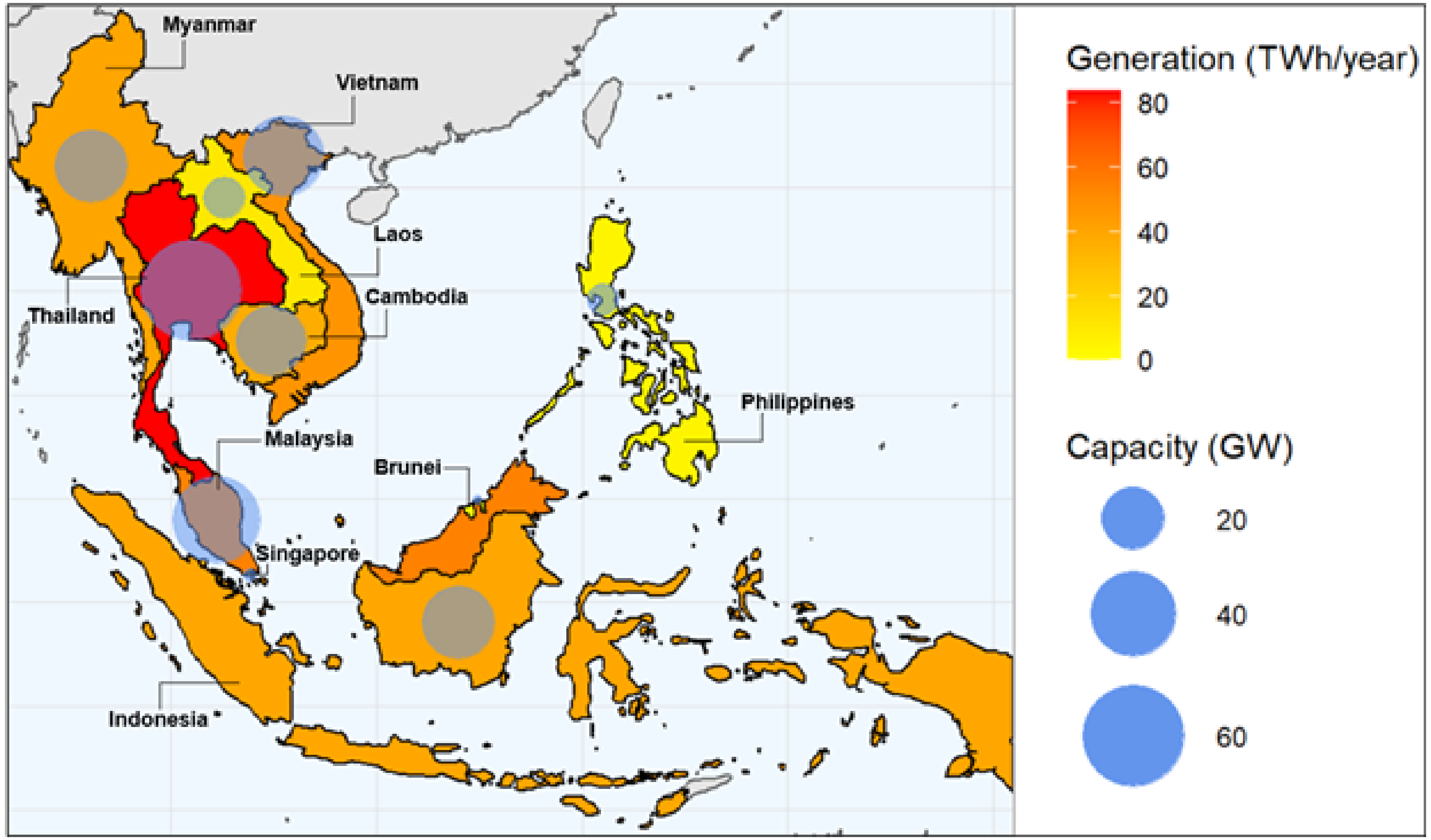

Figure. FPV generation and capacity technical potential for reservoirs in Southeast Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore and 1,000-m maximum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas. These results do not reflect a filter for distance-from-transmission.

Source: Joshi et al. (2023, forthcoming)

Scope of Regional Study

Reservoirs (hydropower and non-hydropower)

Natural waterbodies (e.g., inland lakes, ponds, etc.)

Waterbodies too far from roads (50 km) or in "protected areas" were excluded. Impact of transmission filters (25 km) was also examined for countries that had such data available.

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Potential in Southeast Asia: FPV

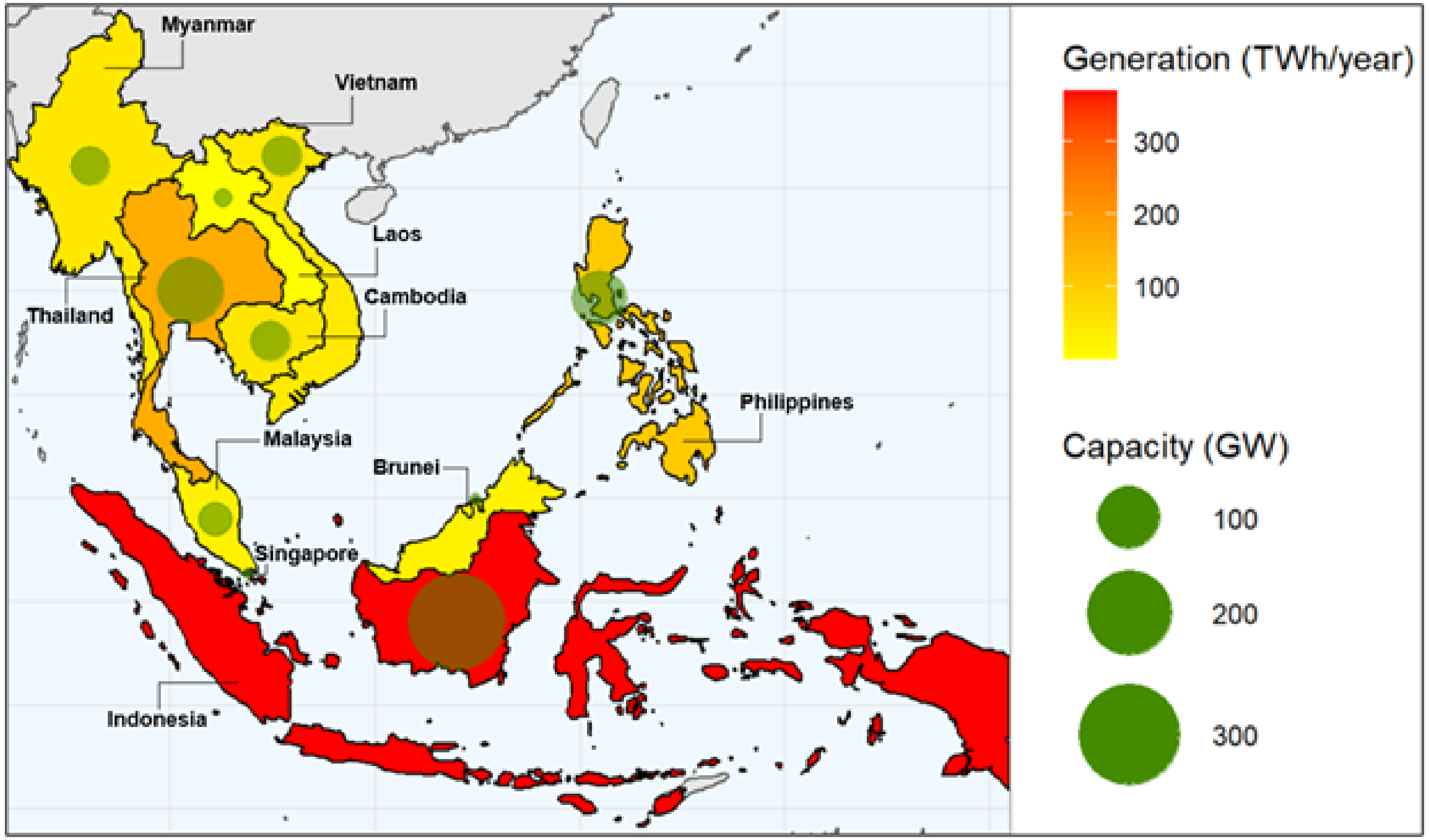

Figure. FPV generation and capacity technical potential for natural waterbodies in Southeast Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore and 1,000-m maximum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas. These results do not reflect a filter for distance-from-transmission.

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Environmental and Cultural Considerations

Barriers

Uncertainty about FPV ecological impacts may increase public opposition to projects and lengthen the environmental review process.

Lack of public buy-in of FPV technology due to visual impacts and competing uses of water bodies could stall project development.

Previous negative experiences with RE projects may lead to an unfavorable public opinion of FPV systems.

Best Practices To Consider

Government support for additional research and development (R&D) and analysis on the environmental impacts of FPV systems could shorten the environmental review process.

Prioritizing obtaining public buy-in and support through public outreach and engagement can avoid delays during the FPV project development process.

Developing educational programs to inform the public about the benefits of FPV systems.

Source: Gadzanku et al. (2021)

Economic Considerations

Barriers

Subsidizing fossil fuels can create an uneven playing field, making it difficult for FPV systems to compete in the market.

Economic policy uncertainty may stall private sector interest in FPV systems.

Trained workforce shortages raise FPV deployment costs.

Best Practices To Consider

Creating clear, complementary, transparent, and consistent incentives for energy development can reduce uncertainty for FPV projects and reduce project development costs.

Consistent and targeted government support to FPV systems in the form of rebates, tax incentives, and competitive RE auctions could help de-risk FPV systems and attract private sector financing.

Source: Gadzanku et al. (2021)

Regulatory Considerations

Barriers

Uncertainty about water rights may delay FPV project development and increase costs.

Lack of interagency cooperation and coordination may stall FPV deployment.

Lengthy, expensive, and unclear environmental approval processes for FPV systems can make projects less financially appealing.

Best Practices To Consider

Clear policies around water rights for FPV projects could reduce uncertainty during the project development process.

Engaging with policymakers and financial institutions to increase awareness of FPV systems can lead to increased support for investing in R&D and deployment projects.

Source: Gadzanku et al. (2021)

Hybrid-Related Considerations

Barriers

Nonexistent or unclear rules on the ownership, market participation, and operation of hybrid hydropower-FPV plants may complicate and stall project development.

Figure. Hydropower dam in Laos

Image: Sherry Stout (NREL)

Best Practices To Consider

Clear regulatory processes on the ownership and market participation models and valuation methods for FPV hydropower hybrid systems.

Development of operational and engineering best practices and training of hydropower plant operators could help ensure smooth operation of these hybrid systems.

Source: Gadzanku et al. (2021)

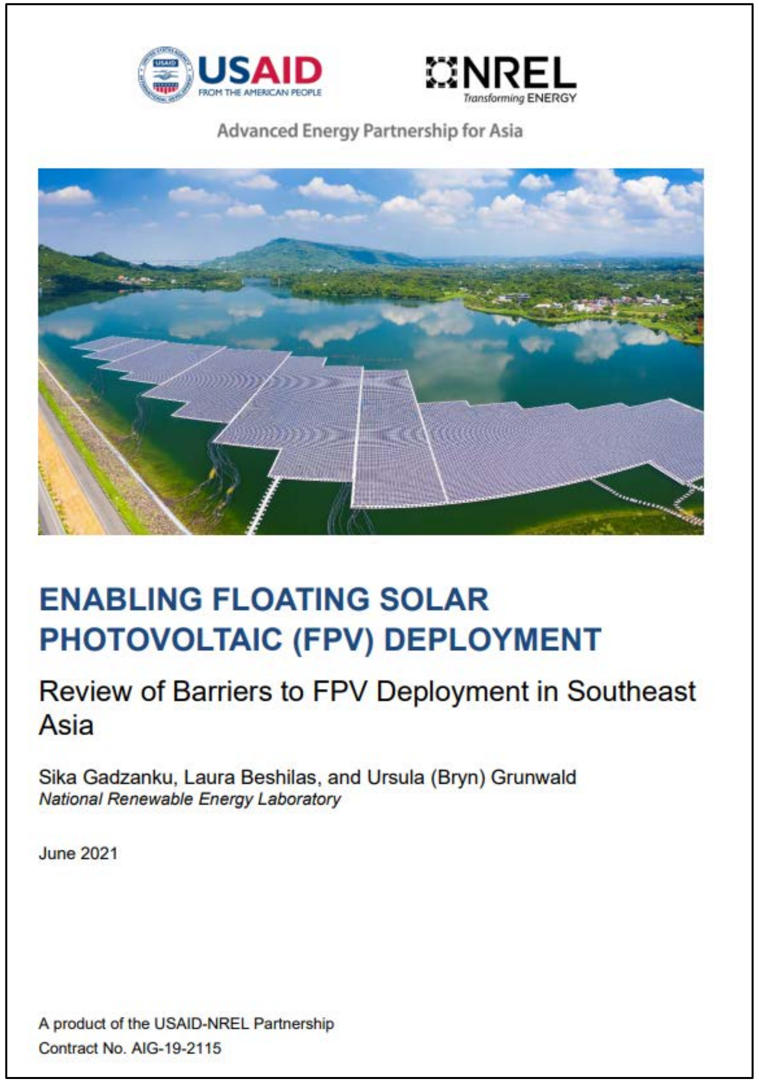
Case Studies: FPV Policies in Asia

Japan: incentivized the deployment of FPV systems in land-constrained areas that had competing land-use needs for agriculture. This allowed populations to ease land-use pressures and align with policies that provided clean and affordable electricity.

South Korea: invested in growing a local, job-creating FPV industry and helped avoid land-energy conflicts caused by land-based PV systems competing with other land-use needs.

Taiwan: created an "AquaPV" policy to incentivize aquaculture farmers to install PV at their farms.

Sources: Gadzanku (2022), Hsaio et al. (2021)



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ENABLING FLOATING SOLAR PHOTOVOLTAIC (FPV) DEPLOYMENT

Review of Barriers to FPV Deployment in Southeast Asia

Sika Gadzanku, Laura Beshilas, and Ursula (Bryn) Grunwald
National Renewable Energy Laboratory

June 2021

A product of the USAID-NREL Partnership
Contract No. AIG-19-2115

Section 2: Select VRE Integration Solution Deep Dives

Energy Storage Fundamentals

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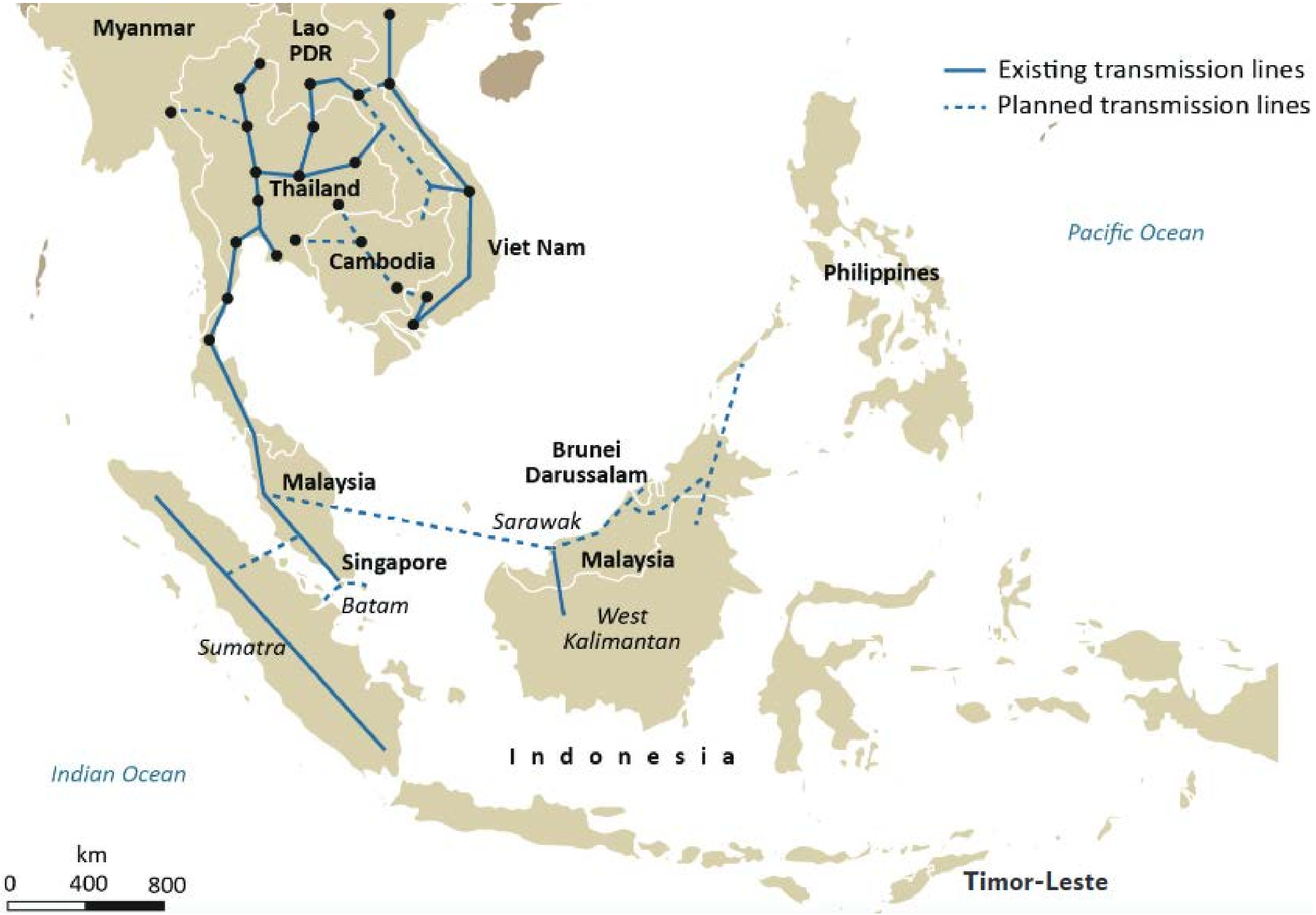
Image: iStock

The Role of Cross-Border Trade

Figure. Existing and planned transmission within the Greater Mekong and Southeast Asia



Source: ADB (2022)

Power trade can expand the geographic diversity of the balancing area to support RE via:

- Larger pool of resources
- More diverse set of generation characteristics
- Seasonal and diurnal optimization of power provision
- Access to clean but non-native resources (wind, hydro, land, etc.)
- Access to low-cost generation options

Important Considerations for CBET

- Historically, cross-border energy trade (CBET) was seen in the light of **resource adequacy.**
- CBET can also help improve grid **reliability** and **resilience** and help reduce **emissions** and **costs.**
- Efficient CBET requires harmonization of practices at various levels:

Institutional: market participation rules, coordinated planning and operations, procedures, framework, dispute resolution, etc.

Regulatory: grid codes, standards, etc.

Technical: joint studies, transfer capability assessment, protection coordination, event analysis coordination, flow control, cybersecurity, data sharing, etc.

Commercial: accounting and settlement, deviation, transmission cost sharing, etc.

What is an Interconnection Study?

An interconnection study aims to **study the impact of a proposed interconnection on the power systems** of the interconnecting countries.

- It could be either a technical or a regulatory assessment study.

Some questions that an interconnection study can answer:

- How does the interconnection provide benefits in the short, medium, and long term?
- How does the interconnection impact the reliability, resource adequacy, and resilience of the system?
- What challenges does an interconnection pose, and how can a system overcome these challenges?
- What is the readiness level for an AC/DC interconnection?
- What should be a road map for cross-border interconnection?

Figure. Hydropower dam substation

Image: Prateek Joshi (NREL)

Case Study: CBET Study for South Asia

Objective: to assess the impact on operational costs of cross border RE trading in South Asia.

- 1,000 MW solar or wind contract from South India (Tamil Nadu) to Bangladesh or Sri Lanka
- 1,000 MW hydro contract from Nepal to Bangladesh.

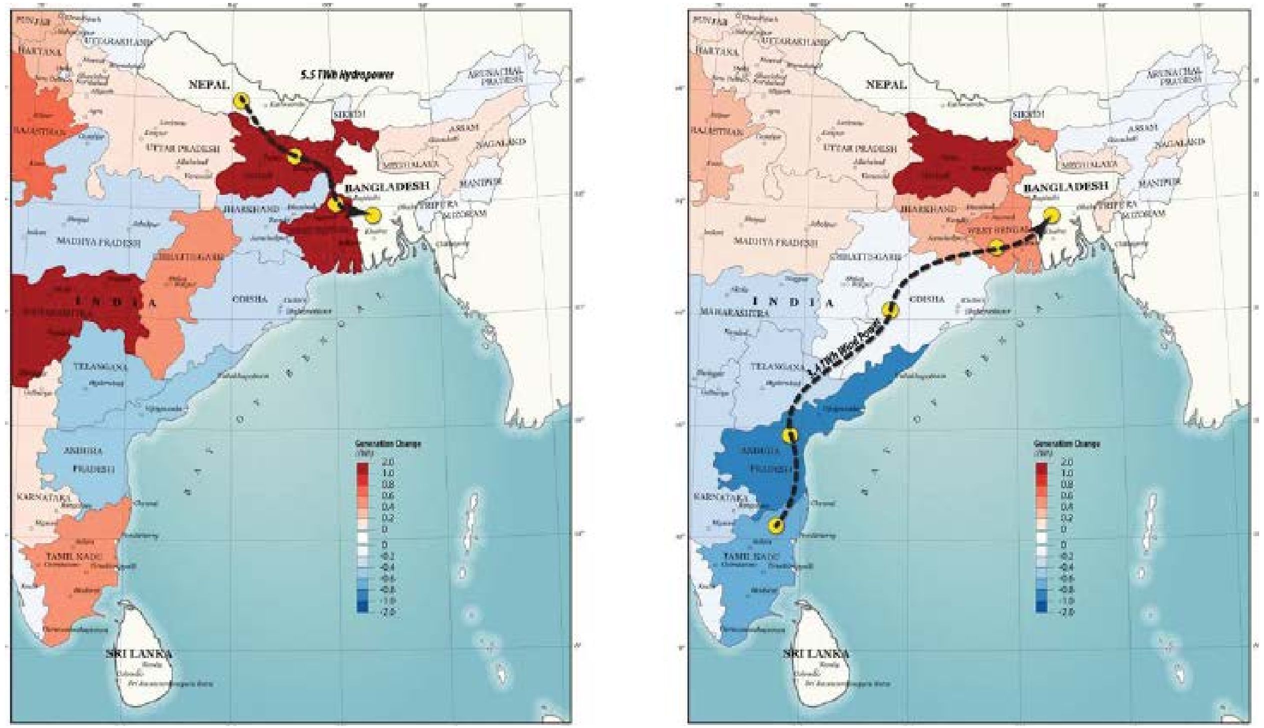
Direct Scenarios

Direct HVDC line from location of RE to the importing country's system.

Indirect Scenarios

Wheeling of RE through the Indian grid to an expanded DC tie between West Bengal and Bangladesh.

Figure. Schematic of CBET scenarios modeled for South Asia



Source: Joshi et al. (2020)

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Implications for Bangladesh

System Balancing: able to balance system with 1,000 MW wind, solar, or hydropower contract.

System Value (production cost savings per unit of generation reduction):

- Wind most valuable, followed by hydropower and solar.

Direct vs. Indirect HVDC: not much difference.

1,000 MW Wind Contract:

- Reduces generation by 4.3%, production cost by 9.5%, and emissions by 5.5%
- Displaces fuel oil by 12%

1,000 MW Solar Contract:

- Reduces generation by 2%, production cost by 3.9%, and emissions by 2.5%
- Displaces fuel oil by 5.5%

1,000 MW Hydropower Contract

- Reduces generation by 7%, production cost by 15%, and emissions by 10%
- Displaces fuel oil by 20%

Source: Joshi et al. (2020)

Implications for Sri Lanka

System Balancing: able to balance system with 1,000 MW wind or solar contract.

System Value (production cost savings per unit of generation reduction):

- 29% more value from solar contract compared to wind contract.

Direct vs. Indirect HVDC: not much difference.

1,000 MW Wind Contract:

- Reduces generation by 7%, production cost by 29%, and emissions by 21%
- Displaces gas generation by 47% and coal generation by 12%

1,000 MW Solar Contract:

- Reduces generation by 1.4%, production cost by 18%, and emissions by 6.3%
- Displaces gas generation by 33%

Source: Joshi et al. (2020)

Implications for Nepal

Hydropower: Nepal's wealth of hydropower could be more valuable to Nepal and its neighbors with greater market integration.

Power Market: participation in an integrated regional power market could help Nepal achieve an economically optimal balance between importing and exporting power.

Figure. Madi River in Nepal

Source: Joshi et al. (2020)

Image: iStock

Implications for India

System Value: negligible impact in terms of generation, production cost, and emissions.

Direct vs. Indirect HVDC: wheeling RE through the Indian grid from Tamil Nadu to Bangladesh results in slightly less generation in the Southern and Western regions and slightly more generation in the Eastern and Northern Regions.

Figure. Solar power plant in India

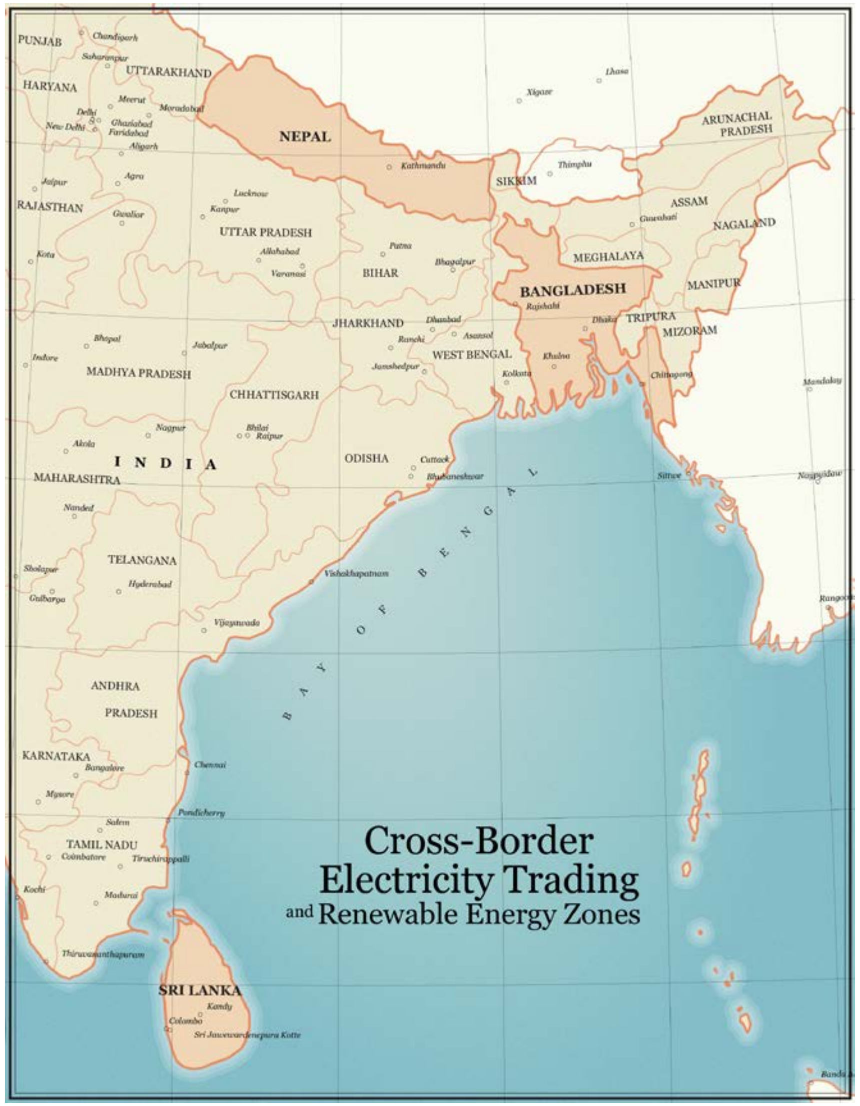
Source: Joshi et al. (2020)

Image: Prateek Joshi (NREL)

Implications for the South Asia Region

- India's national RE zones for wind and solar PV and Nepal's hydropower could become regional green power resources if South Asian countries liberalize their rules for CBET.
- An integrated bulk power system in South Asia could improve resilience, increase benefits to customers, increase economic efficiency, and result in a greener grid.
- Combining domestic RE with imported wind, PV, and hydropower could accelerate decarbonization and reduce generation costs in South Asia.
- Wheeling power through India's grid appeared to offer the same operational benefits as building a separate line to bypass the main grid altogether, as long as there is no institutional restraint on moving power between countries.

Figure. Region for CBET case study



Source: Joshi et al. (2020)

Image: Billy Roberts (NREL)

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Thank You!

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