Webinar on Optimal Sizing and Placement of Batteries for Solar Acquisition

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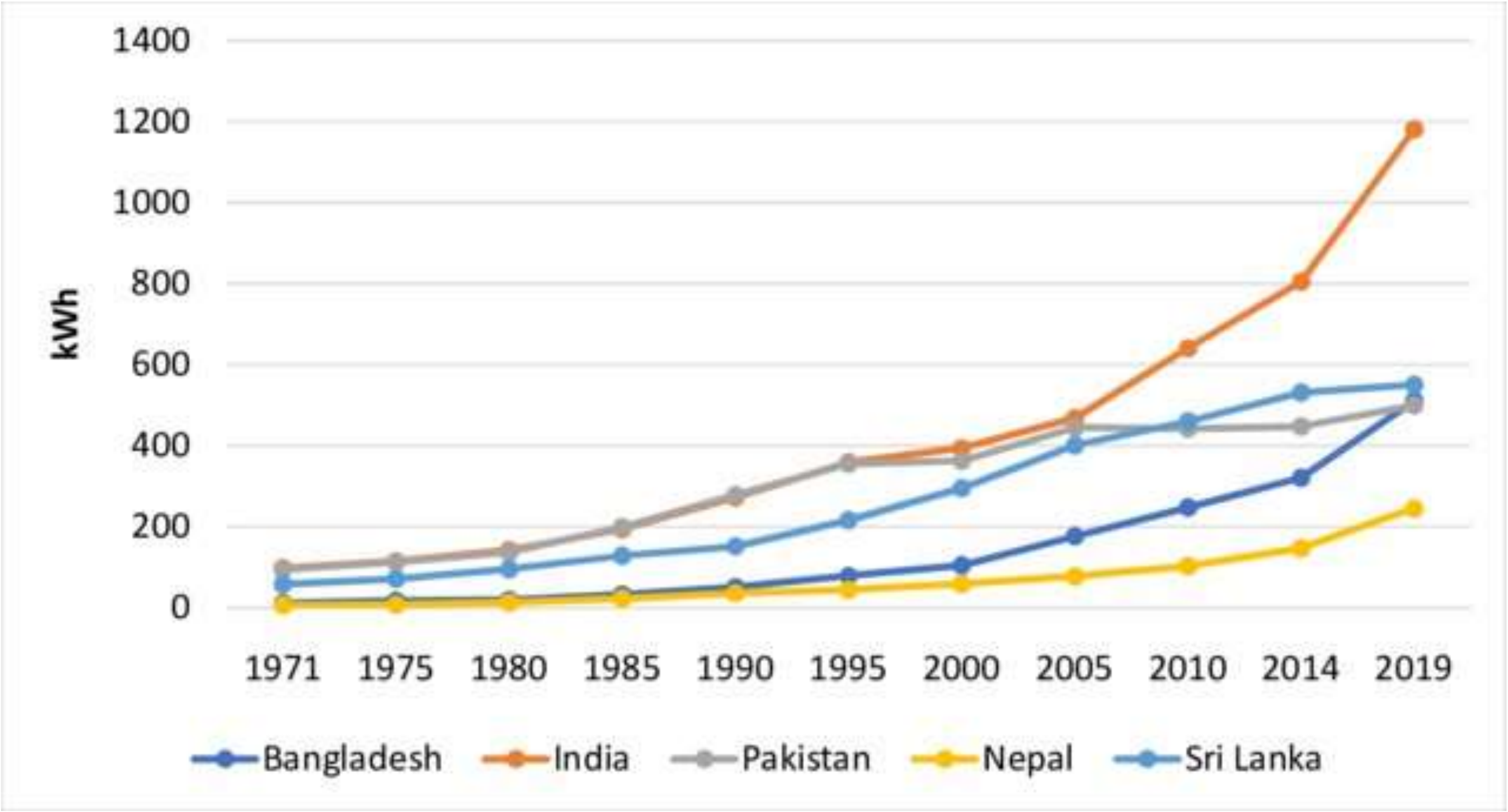
Table of Contents

Regional Energy Challenges

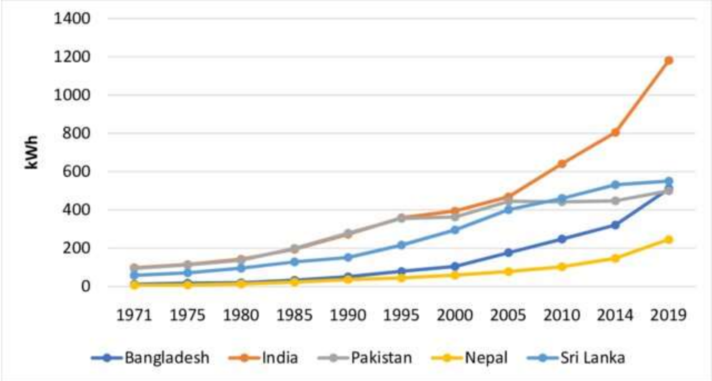
- Increase in per capita electricity generation among SAARC member countries

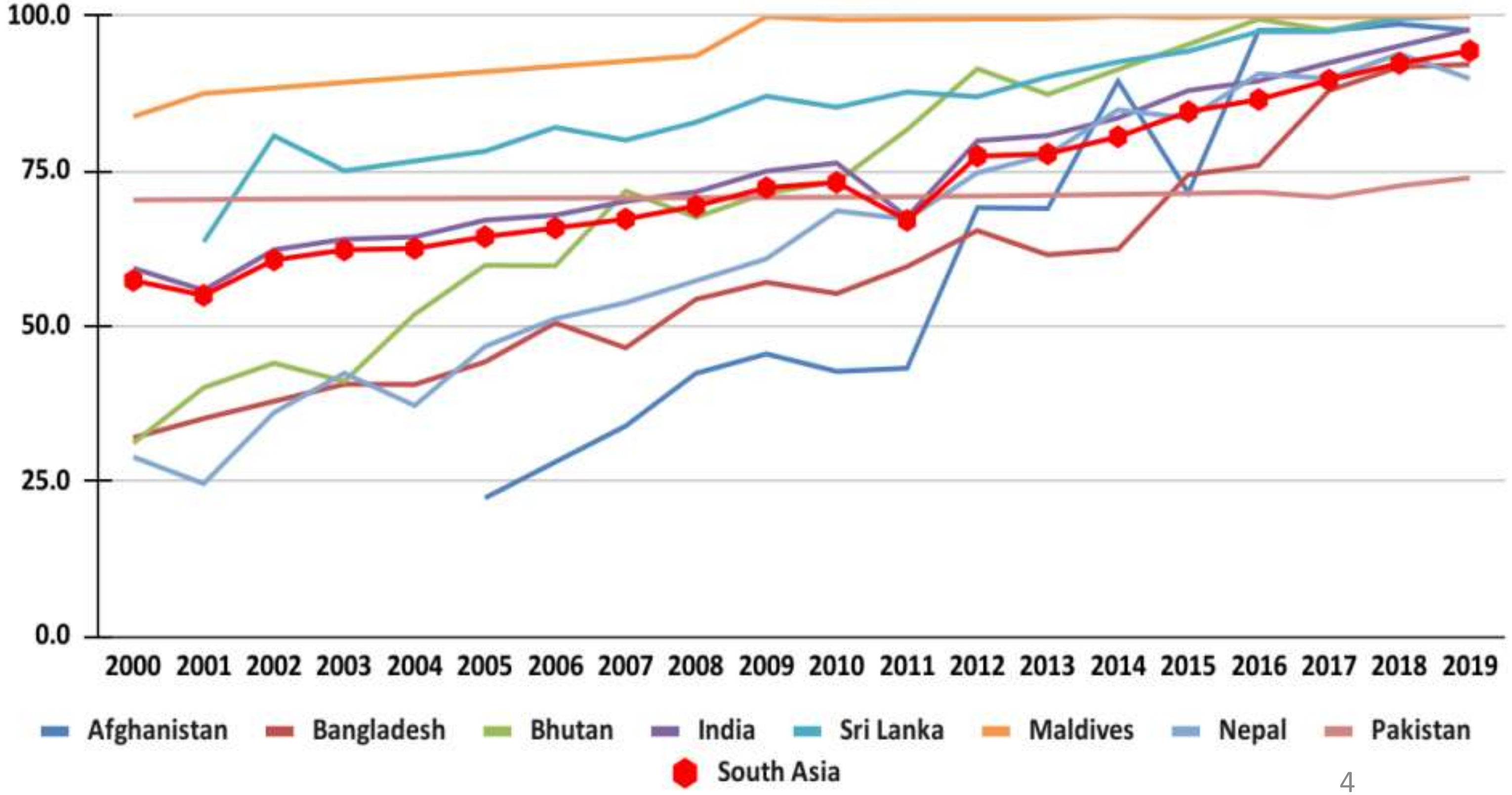


DOI: 10.13140/RG.2.2.28191.74400

Regional Energy Challenges

- Increase in per capita electricity generation among SAARC member countries
- The electric power consumption of South Asia has also increased to 1,015 kWh per capita, it is still much less than the global average of 2,674 kWh per capita





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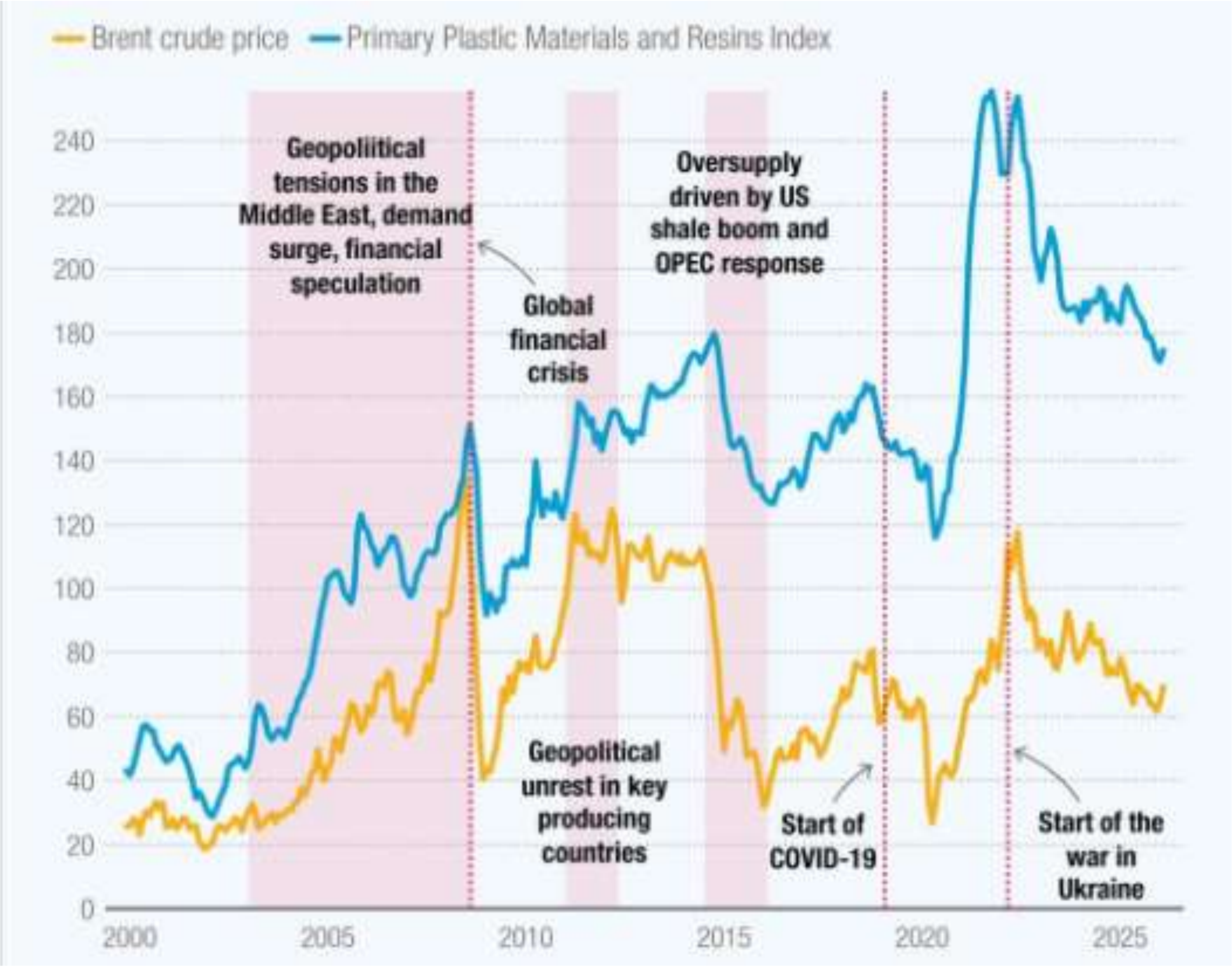
Regional Energy Challenges

- Pakistan is 61% dependent on thermal power plants
- Coal contributes to 54.59% electricity production in India
- Bangladesh is dependent on gas 53.86% and furnace oil 27.18% for electricity generation
- Maldives, about 96% of generation is through oil

Country	Installed Generation Capacity (MW)	Major Fuel Type
Afghanistan	1,341	❖ Hydro and Oil Dominated ❖ High Electricity Imports
Bangladesh	25,171	❖ Gas & furnace oil dominated
Bhutan	2,326	❖ Hydro Dominated
India	383,373	❖ Coal Dominated ❖ Rapidly increasing Renewable energy -133 GW
Nepal	1,280	❖ Hydro Dominated
Pakistan	38,719	❖ Gas, Oil and Hydro dominated
Sri-Lanka	4,086	❖ Hydro and oil dominated
The Maldives	366	❖ Oil, Diesel dominated
Total Electricity Installed Capacity of SMS	**4,56,662**	❖ Overall dominated by Fossil fuel

Regional Energy Challenges

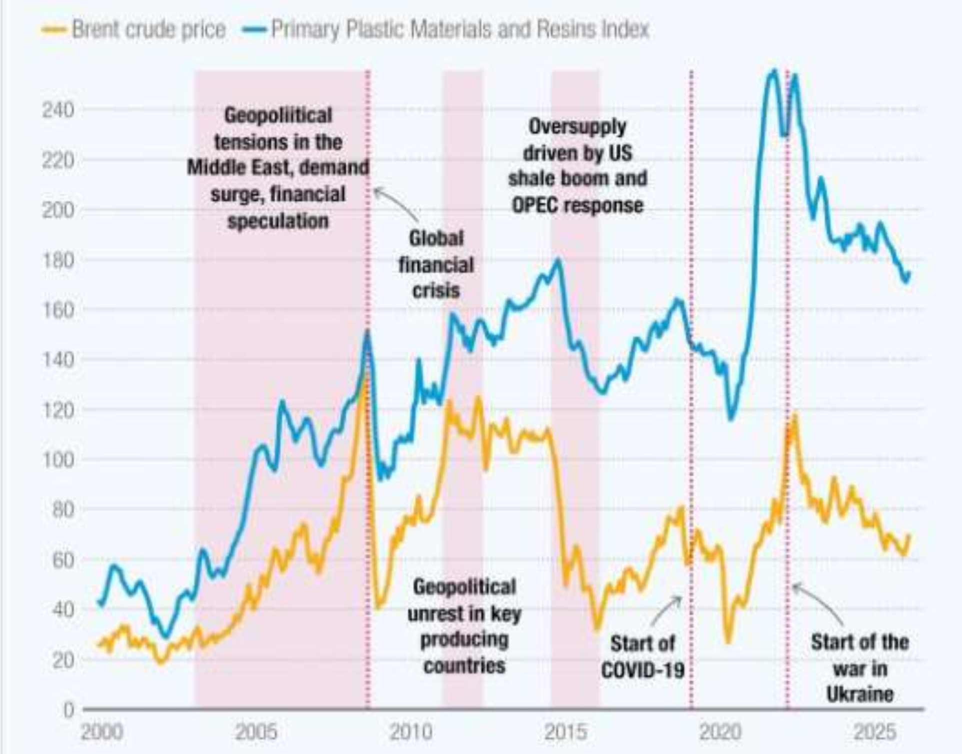
- ❑ Geopolitical conflicts and international crises (e.g., wars, trade disputes, and shipping disruptions) often trigger sharp increases in oil and natural gas prices
- ❑ Dependence on imported fossil fuels exposes SAARC countries to global fuel price volatility and supply disruptions



UN Trade and Development, UNCTAD

Regional Energy Challenges

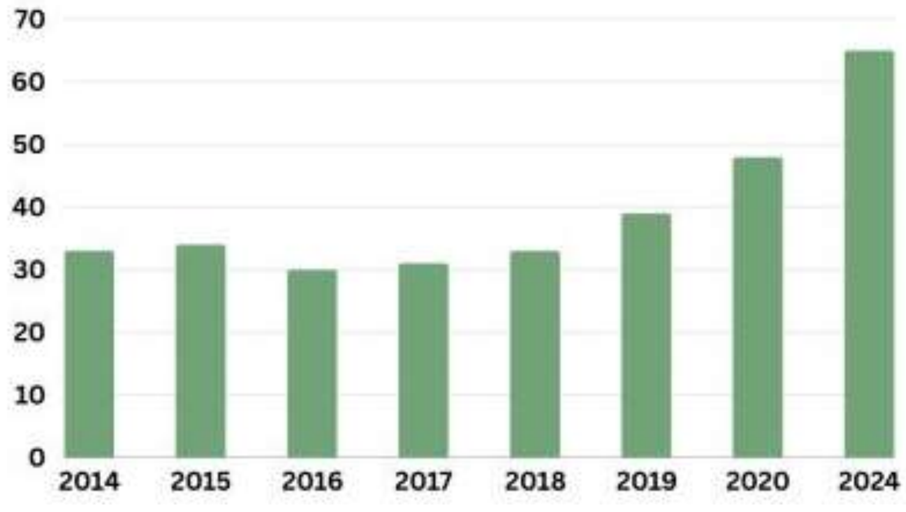
- Rising fuel costs increase electricity generation costs, strain national economies

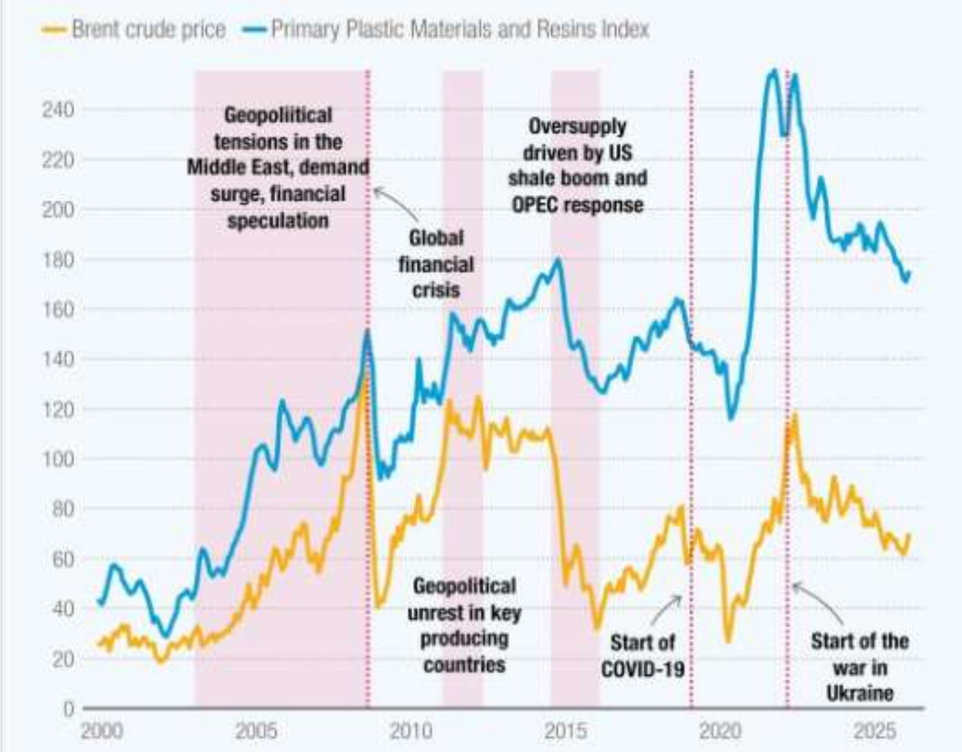


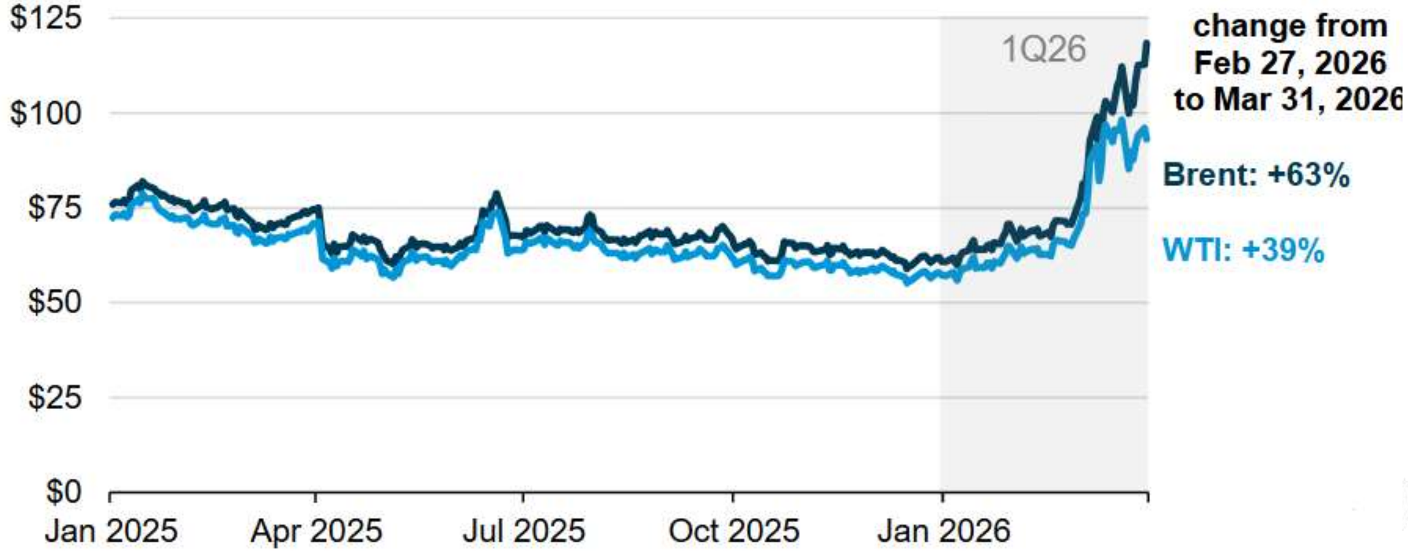
UN Trade and Development, UNCTAD https://www.eia.gov/todayinenergy/detail.php?id=67424 Climate Finance Pakistan

Regional Energy Challenges

- ❑ Rising fuel costs increase electricity generation costs, strain national economies
- ❑ Cost of electricity has risen 116% in Pakistan over the last 8 years



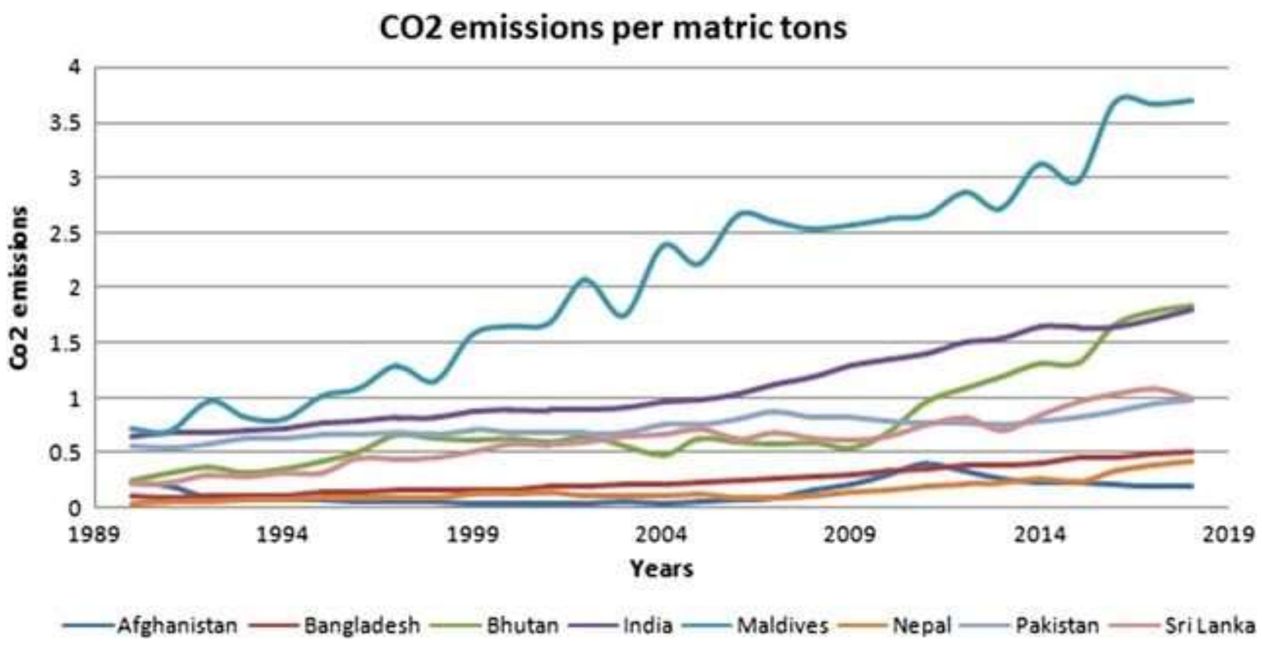


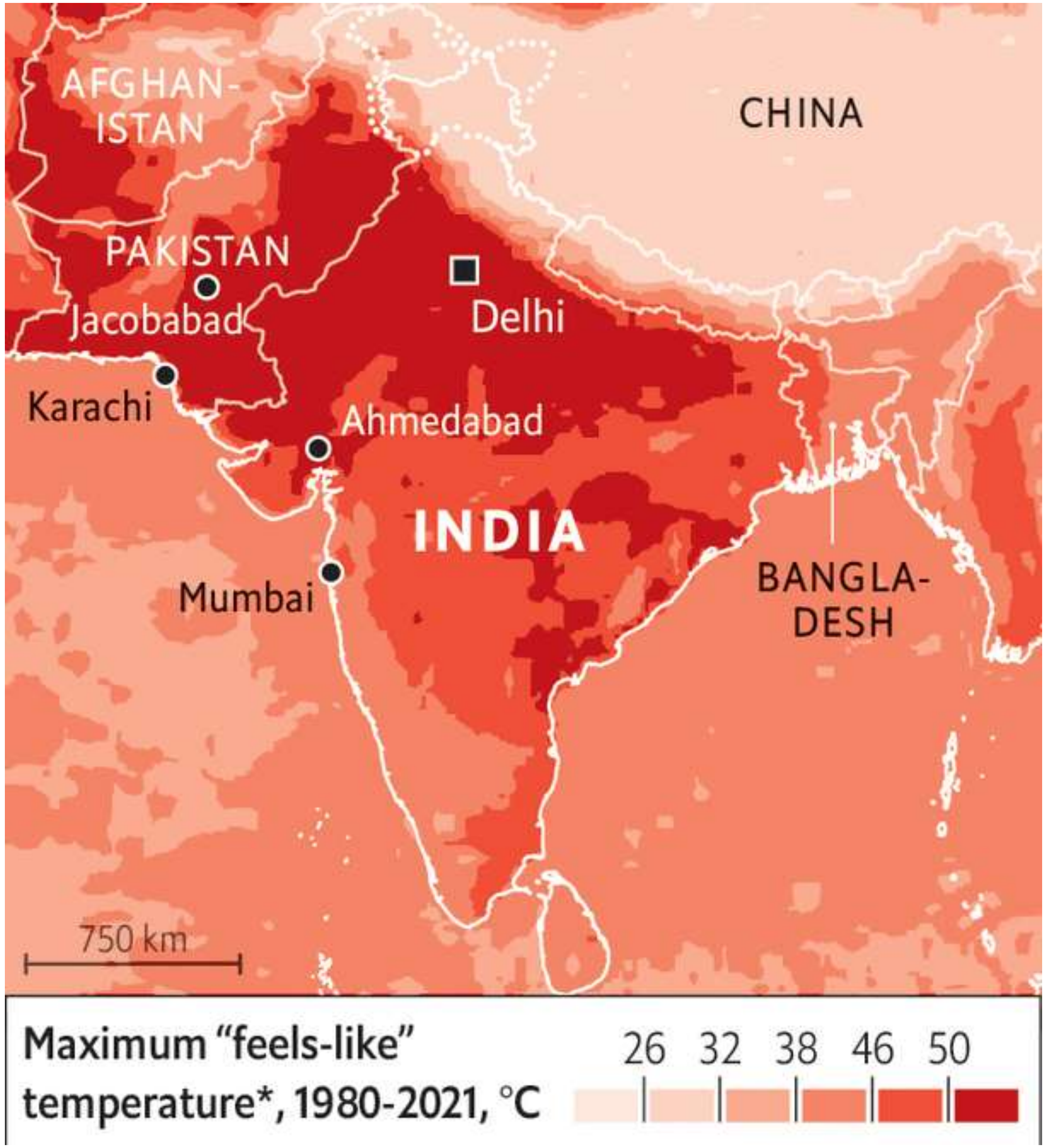


UN Trade and Development, UNCTAD https://www.eia.gov/todayinenergy/detail.php?id=67424 Climate Finance Pakistan

Regional Energy Challenges

- Fossil fuels are a major source of greenhouse gas (GHG) emissions, causing global warming
- Increasing global temperatures are driving more frequent and severe climate events, including heatwaves, floods, droughts, and extreme storms.





DOI: 10.1007/s10668-022-02676-x

Need of Renewable Energy

- **Renewable energy** reduces fossil fuel reliance, lowering emissions and improving air and water quality

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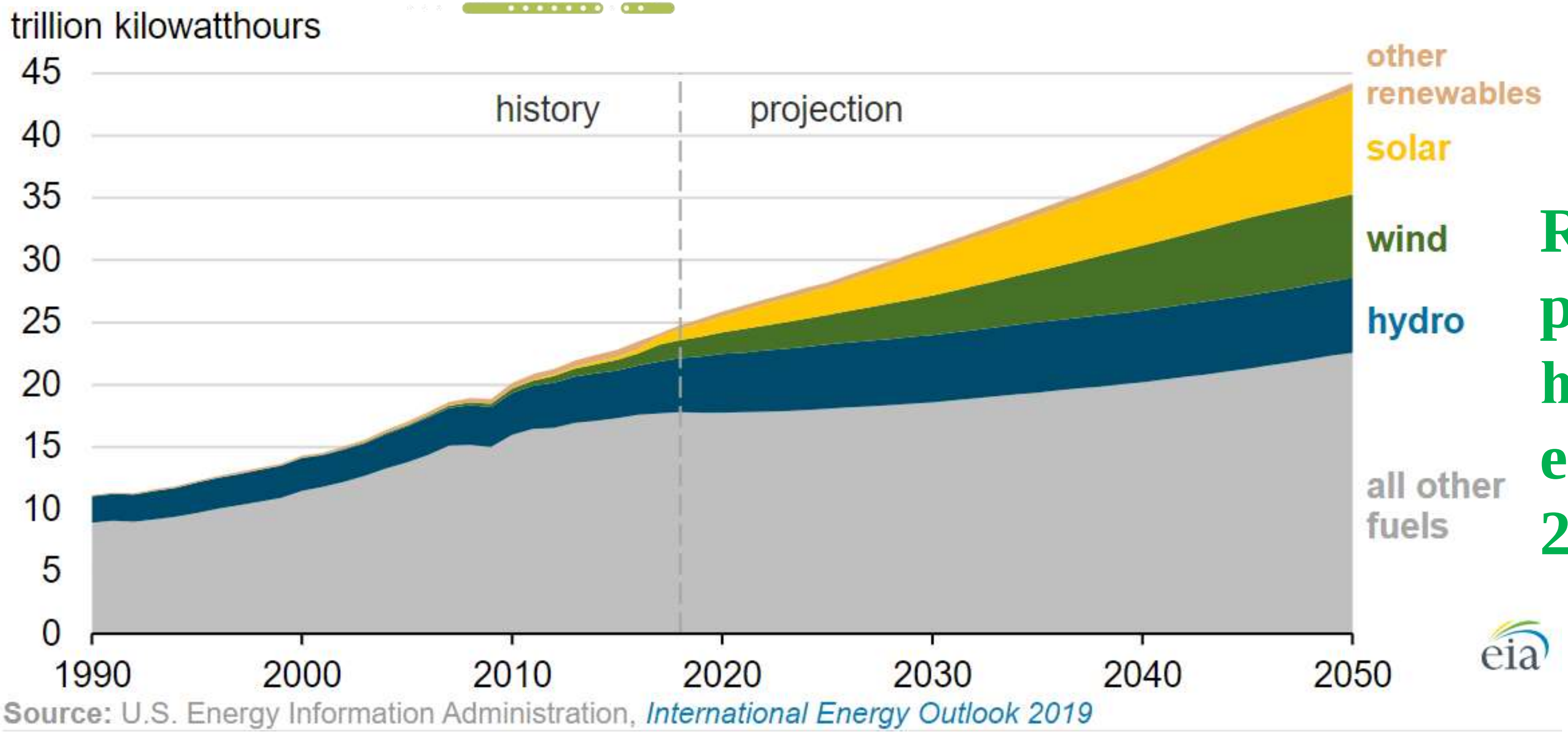
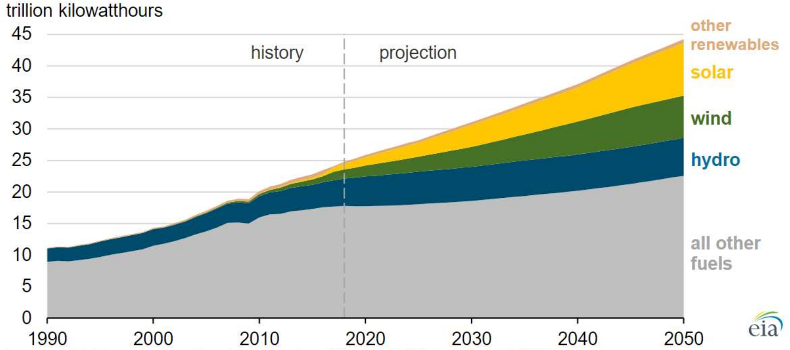


Renewables will provide nearly half of world's electricity by 2050

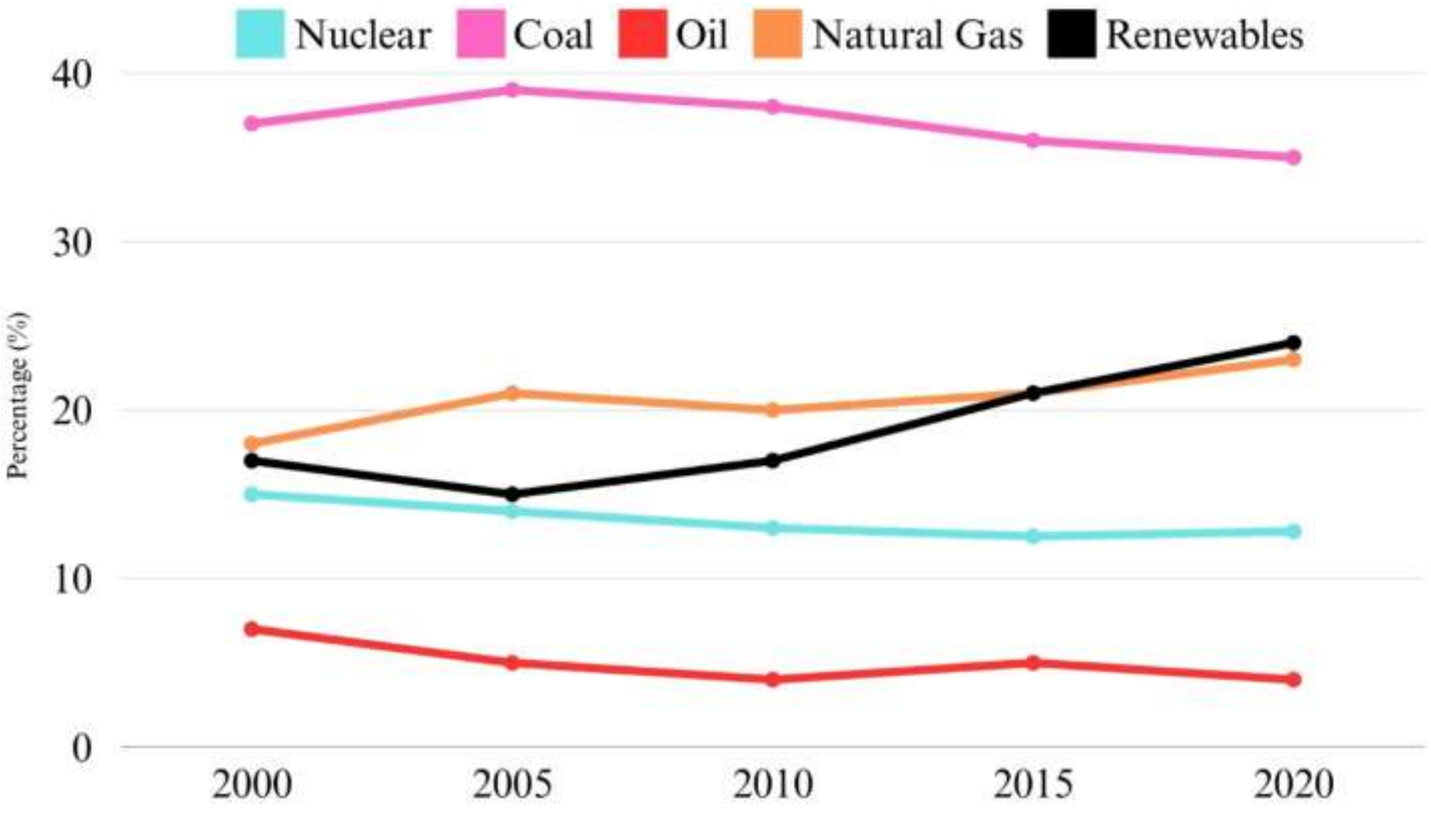
Need of Renewable Energy



Source: U.S. Energy Information Administration, *International Energy Outlook 2019*

Renewables will provide nearly half of world's electricity by 2050

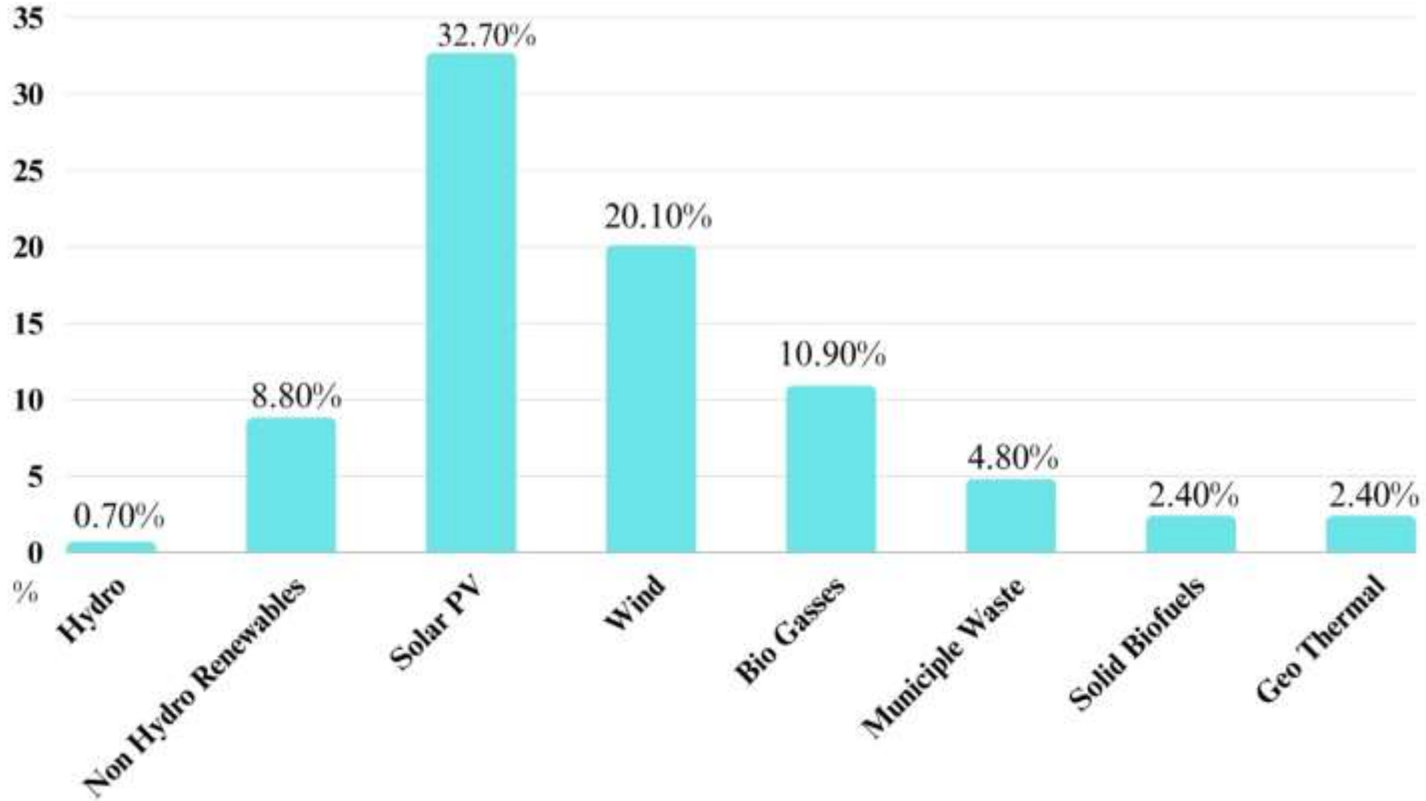
- The percentage of power produced by renewables has increased substantially in recent years



https://www.sciencedirect.com/science/article/pii/S0301421525004252

Need of Renewable Energy

- ❑ Wind and solar PV power are the primary forms of renewable energy generation in SAARC nations
- ❑ Their growth has been accelerating

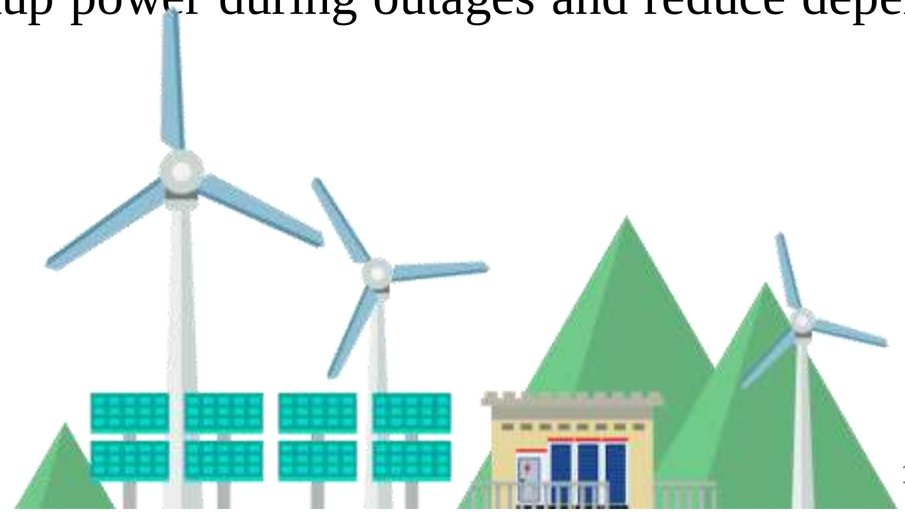


✓ **Intermittency of renewable energy resources depends on Energy Storage Systems**

https://www.sciencedirect.com/science/article/pii/S0301421525004252

Battery Energy Storage System

- **Mitigate Solar Variability**: Store excess solar energy during the day and supply it when solar generation is low or unavailable.
- **Enhance Grid Stability**: Provide frequency regulation, voltage support, and fast response to grid disturbances.
- **Reduce Renewable Energy Curtailment**: Capture surplus renewable energy instead of wasting it.
- **Meet Peak Electricity Demand**: Shift stored energy to periods of high demand, reducing reliance on expensive peaking power plants.
- **Improve Energy Security and Reliability**: Provide backup power during outages and reduce dependence on imported fossil fuels.



Battery Energy Storage System

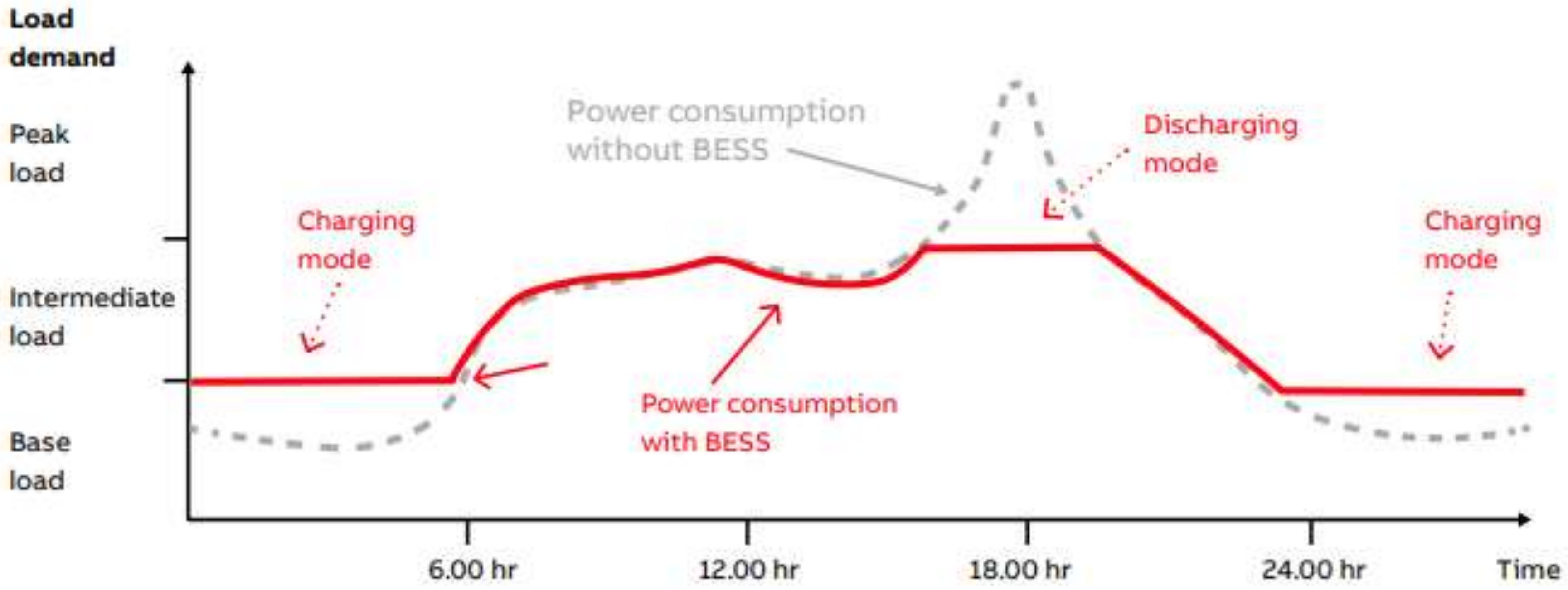
- A **Battery Energy Storage System (BESS)** converts electrical energy into chemical energy during charging and reconverts it into electrical energy during discharge
- BESS stores electrical energy and releases it when needed, improving the reliability and flexibility of the power system
- A typical **BESS consists** of battery modules, a Battery Management System (BMS), an Energy Management System (EMS)
- The BMS and EMS continuously monitor battery health, temperature, voltage, and state of charge to ensure safe, reliable, and efficient operation

Battery Energy Storage System

Feature	Lead-Acid	Lithium-ion	Flow Battery
Technology	Flooded, Gel	LFP, NMC, LCO, NCA	Redox, Hybrid
Typical Application	Small/off-grid systems	Residential, Commercial, Utility	Utility-scale, Long-duration storage
Energy Density	Low	High	Low
Round-Trip Efficiency	70–85%	90–98%	70–90%
Depth of Discharge (DoD)	50–80%	80–98%	Up to 100%
Charging Speed	Slow	Fast	Moderate–Fast
Lifetime	3–7 years	10–20 years	20–30+ years
Maintenance	High	Low	Low–Moderate
Safety	Safe with proper handling	High (with BMS)	Very safe, low fire risk
Advantages	Low cost, mature technology	High efficiency, compact, lightweight, ideal for solar & EVs	Long life, non-toxic, scalable, ideal for long-duration storage
Limitations	Short life, low performance at high temperatures	Thermal management required	Low energy density
Relative Cost	Low	Medium - high	High

Role of BESS in Power System Operation

- **Balances generation and demand** by storing surplus energy and supplying power during peak demand
- **Facilitates renewable energy integration** by mitigating the intermittency and variability of solar and wind generation
- **Provides ancillary services**, including frequency regulation, voltage support, spinning reserve, and black start capability
- **Enhances grid reliability and resilience** by improving power quality, reducing outages, and providing backup power
- **Optimizes power system operation** through peak shaving, load shifting, congestion relief, and transmission & distribution (T&D) deferral



Optimal Battery Sizing vs. Optimal Battery Placement

Feature	Optimal Sizing	Optimal Placement
Key Question	**How much storage is needed?**	**Where should the BESS be installed?**
Decision Variable	Battery capacity (kWh) & power rating (kW)	Generation, Distribution, or Behind-the-Meter (BTM)
Main Objective	Minimize cost while meeting energy and power requirements	Maximize grid performance and economic benefits
Key Factors	Load profile, solar generation, battery duration, budget	Grid topology, renewable penetration, congestion, voltage profile
Poor Optimization	Oversized → High cost Undersized → Poor performance	Poor location → Reduced grid benefits and lower ROI
Expected Outcome	Optimum battery size	Optimum installation location

Optimal Battery Sizing

Techno-Economic Optimization of Battery Energy Storage Systems

Techno-economic optimization identifies the battery size and placement that provide the best balance between technical performance and economic returns while satisfying system constraints

- **Objective**: Minimize total lifecycle cost or maximize project value (e.g., NPV, ROI, renewable utilization).
- **Technical Constraints**: Battery capacity, power rating, State of Charge (SoC), grid limits, reliability requirements.
- **Economic Factors**: Capital cost, operating & maintenance (O&M) cost, electricity tariffs, battery degradation, replacement cost.
- **System Uncertainties**: Variations in solar generation, electricity demand, market prices, and battery aging.
- **Multi-Objective Optimization**: Simultaneously balances cost, reliability, renewable integration, and environmental benefits.

The optimal BESS design is not necessarily the cheapest or the largest - it is the solution that best satisfies technical requirements while maximizing economic value over the project lifetime.

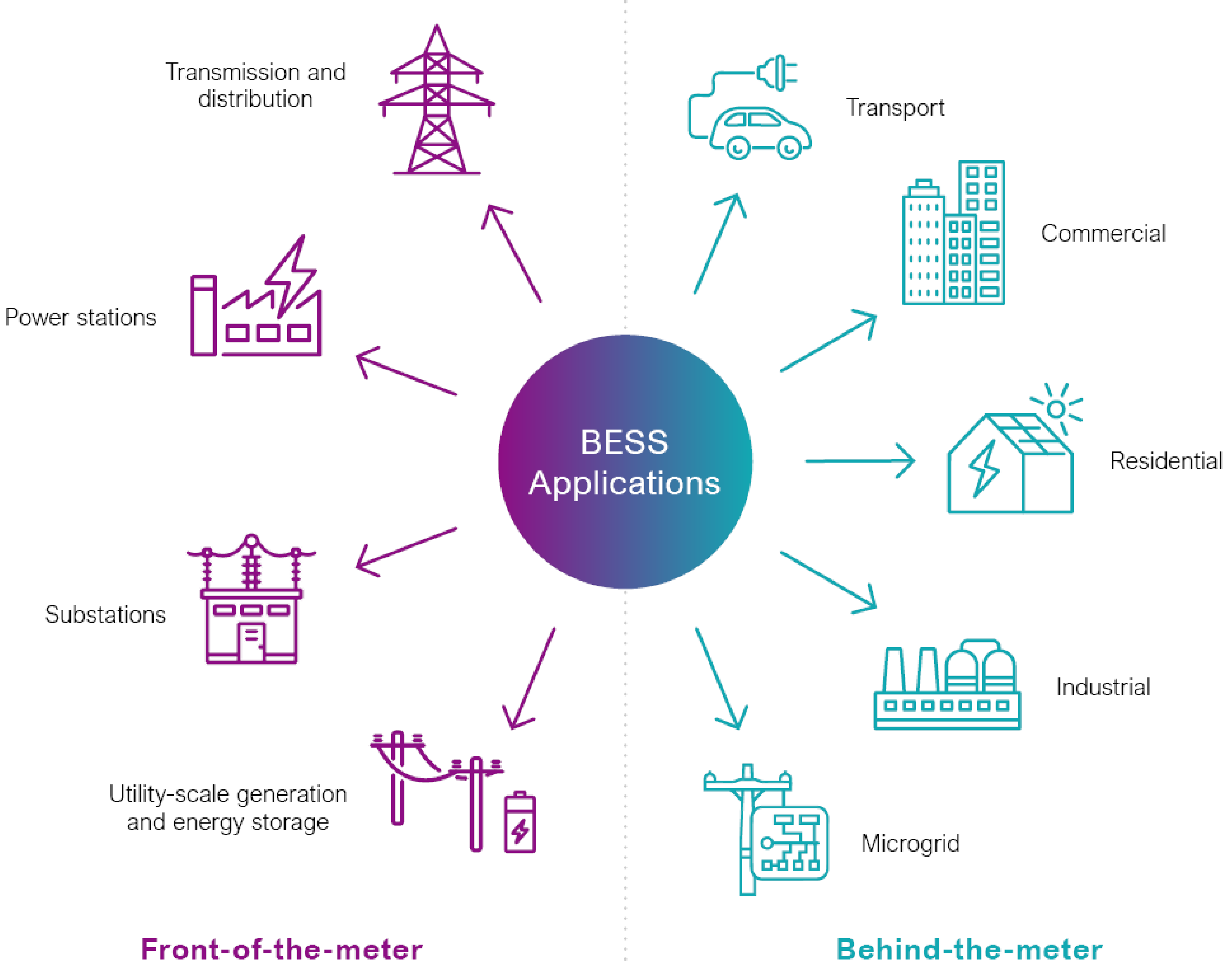
Key Decision Metrics for BESS

Metric	Purpose
LCOS (Levelized Cost of Storage)	Measures the lifetime cost per unit of electricity delivered from the battery.
NPV (Net Present Value)	Determines the overall economic profitability of the project.
IRR (Internal Rate of Return)	Indicates the expected return on investment.
Payback Period	Time required to recover the initial investment.
Avoided Cost	Savings from reduced peak demand, fuel consumption, and deferred grid upgrades.
Reliability Value	Benefits from improved grid reliability, resilience, and backup power.
Congestion Relief	Economic value of reducing transmission and distribution network constraints.
Tariff Impact	Savings through demand charge reduction, energy arbitrage, and time-of-use (TOU) pricing.

Data Requirements for BESS Planning and Optimization

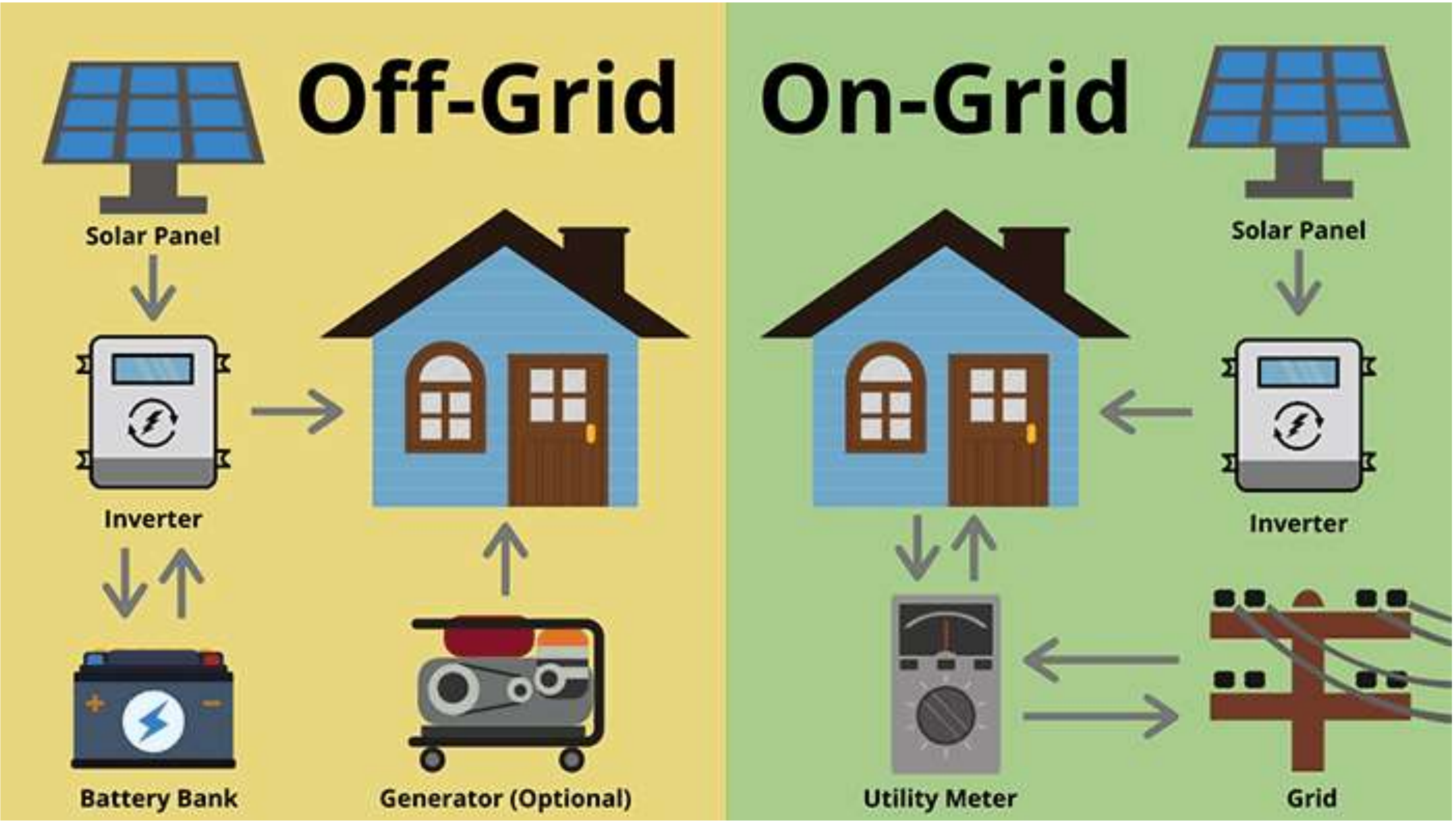
Data Type	Purpose
Load Profile	Analyze demand patterns and peak loads.
Solar Generation Profile	Assess renewable energy availability and variability.
Grid Topology & Feeder Limits	Identify optimal BESS location and network constraints.
Outage & Reliability Data	Evaluate backup power and resilience requirements.
Electricity Tariffs & Market Prices	Optimize operational strategy and project economics.
Battery Technical Parameters	Assess capacity, efficiency, degradation, and lifetime.

BESS Placement



https://www.beca.com/ignite-your-thinking/ignite-your-thinking/october-2024/exploring-battery-energy-storage-systems-role-in-the-future-of-energy

Behind-the-Meter (BTM) Applications of BESS

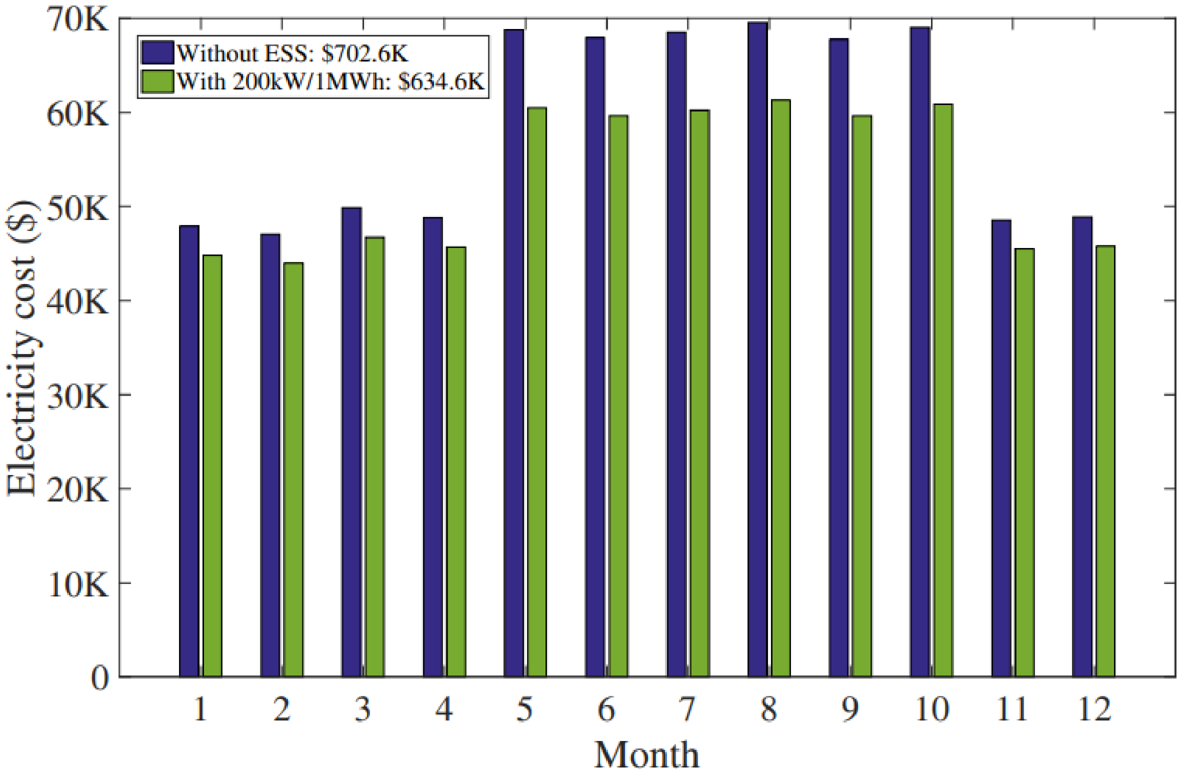


On-Grid BTM Application of BESS

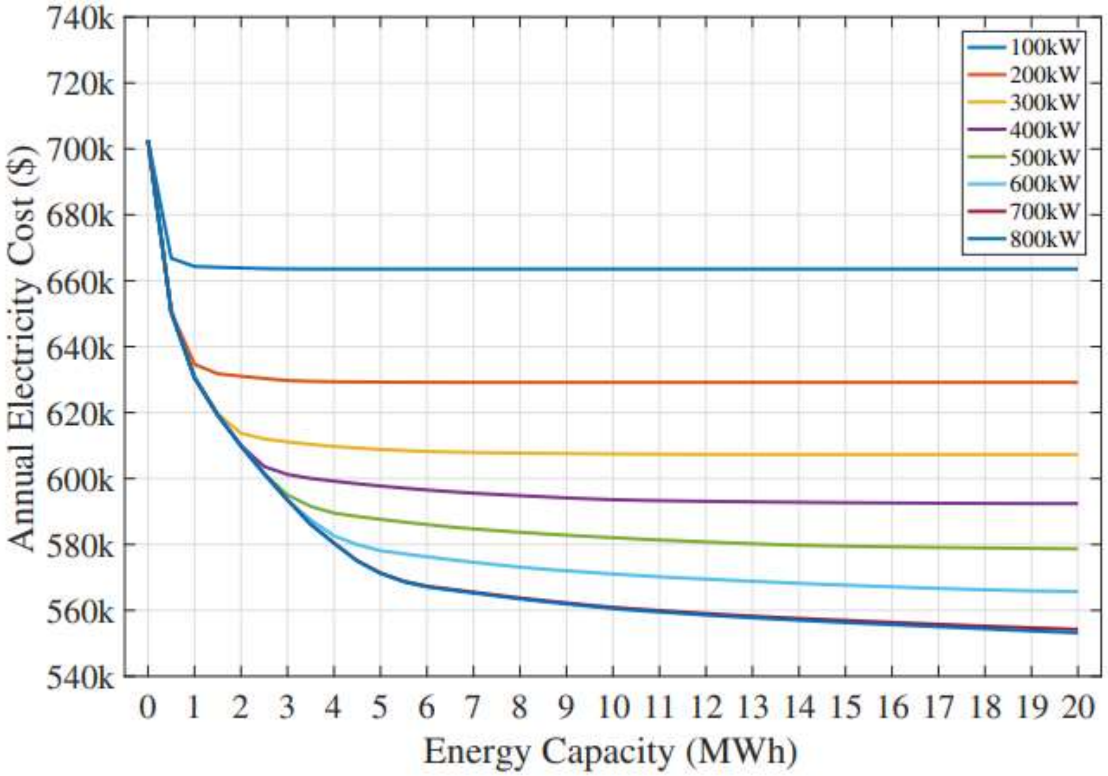
- **Installed at residential, commercial, and industrial facilities** to optimize on-site energy use.
- **Stores excess rooftop solar energy** for use during peak demand or when solar generation is unavailable.
- **Reduces electricity costs** through peak shaving, load shifting, and Time-of-Use (TOU) tariff optimization.
- **Provides backup power** during grid outages, improving business continuity and energy resilience.
- **Enhances power quality and increases self-consumption** of renewable energy while reducing dependence on the grid.

On-Grid BTM Application of BESS

A Medium Size Commercial Customer



Monthly electricity bills with/without 200kW/1MWh BESS



Sensitivity of annual electricity bill to BESS size

https://ieeexplore.ieee.org/abstract/document/8107380

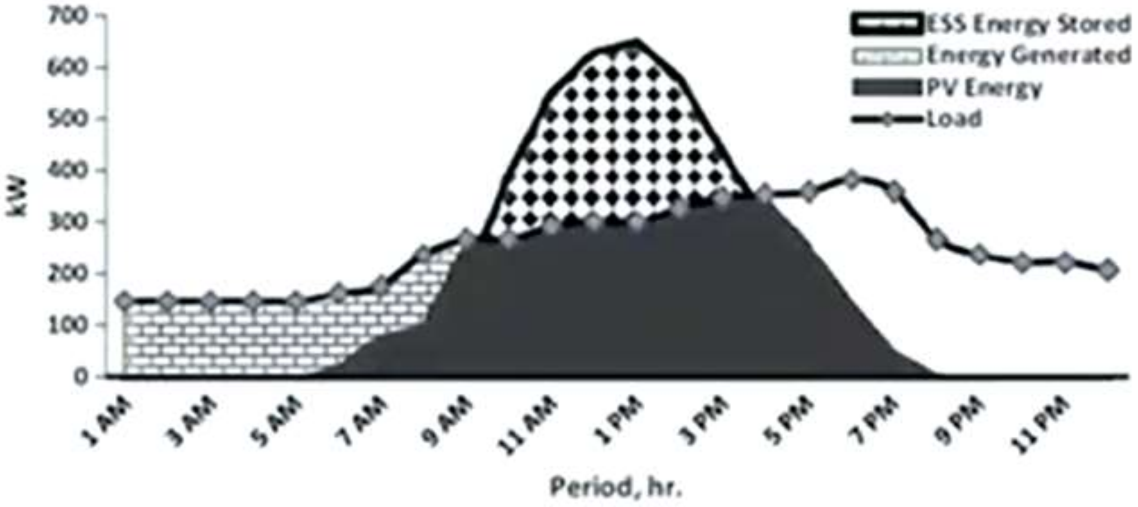
Off-Grid BTM Application of BESS

- Battery sizing is based on **daily energy demand, autonomy period, and solar resource availability**.
- Proper sizing ensures **24/7 electricity supply** during nighttime and cloudy weather.
- **Enables reliable electricity** access in remote and islanded communities.
- **Stores excess solar energy** for use during nighttime and cloudy periods.
- **Reduces dependence** on diesel generators, lowering fuel costs and emissions.
- **Improves energy resilience** for schools, healthcare centers, telecom towers, and rural industries.
- **Supports hybrid renewable energy systems** (Solar PV + BESS + Diesel backup, where needed).

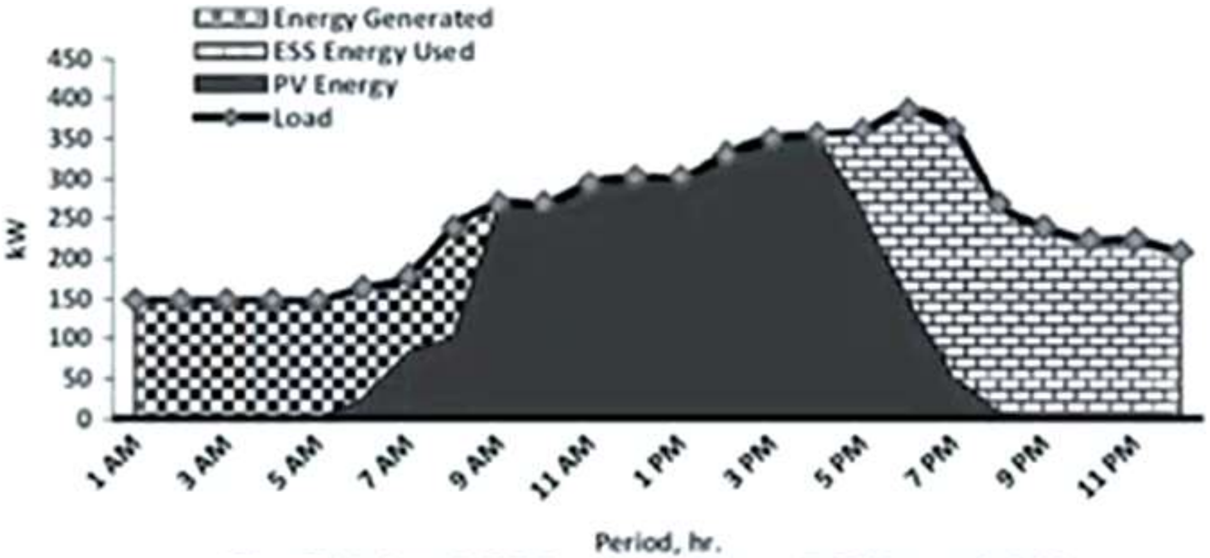
BESS in Low- and Medium-Voltage Distribution Networks

- Facilitates higher integration of distributed renewable energy (DERs), particularly rooftop solar PV, while maintaining reliable network operation.
- Stores surplus renewable energy during periods of high generation and supplies it during peak demand, enabling energy time-shifting and load balancing.
- Improves voltage regulation, power quality, and overall system reliability in distribution networks.
- Reduces feeder congestion, transformer loading, and technical losses, thereby improving distribution system efficiency.
- Defers or avoids costly investments in distribution infrastructure, including feeder reinforcement, transformer upgrades, and substation expansion.
- Enhances grid observability and controllability through integration with advanced communication, monitoring, and Energy Management Systems (EMS).Supports microgrids and off-grid electrification, improving energy access and system resilience.

BESS in Low- and Medium-Voltage Distribution Networks



Storing excess PV energy in BESS from 9 AM to 4 PM



Using BESS energy from 5 PM to 12 AM

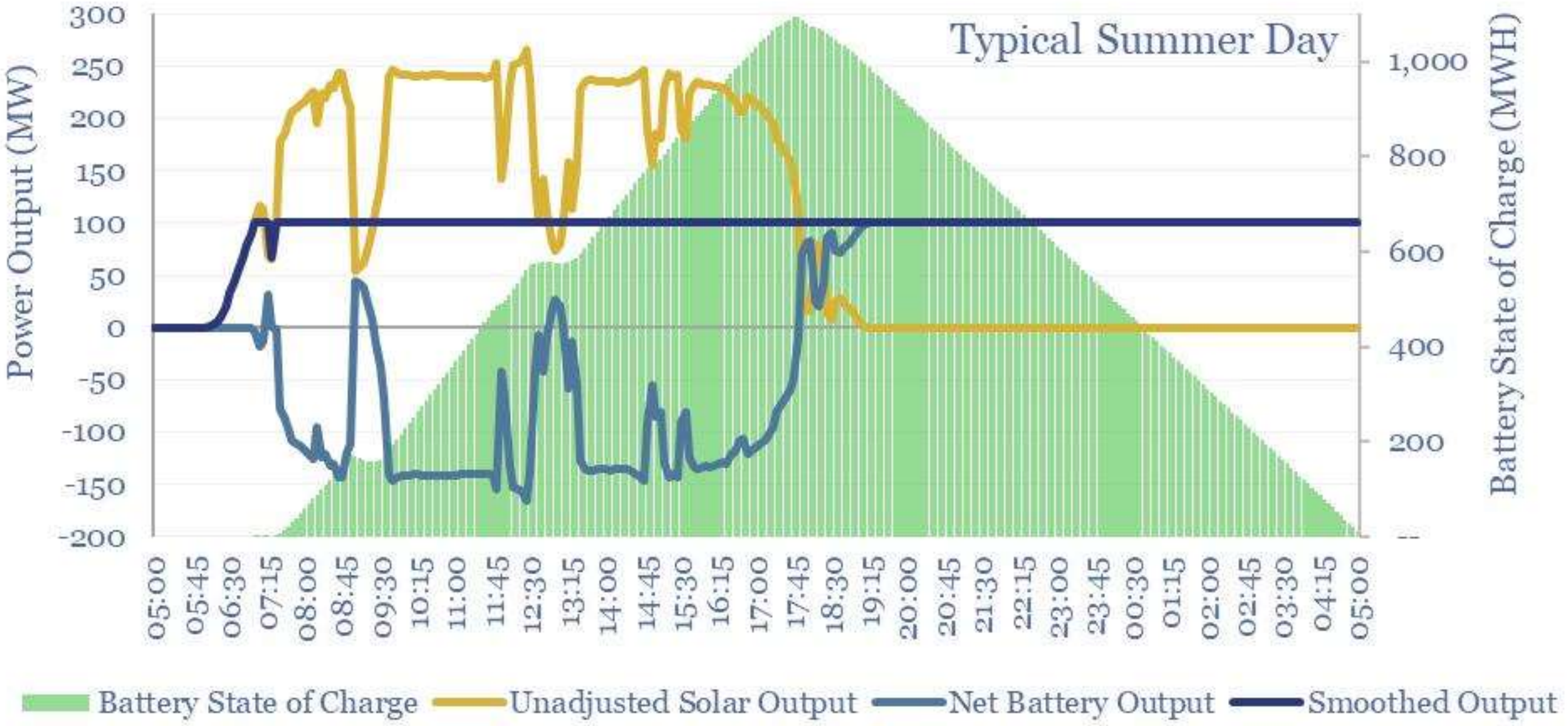
- Utility uses generator and PV systems to meet 24-hour load demand. Excess PV energy is stored in BESS.
- BESS energy is used from 5 PM to 12 AM, reducing dependency on the generator after 9 PM, saving energy costs.

https://link.springer.com/chapter/10.1007/978-3-030-36115-0_5

Utility-Scale and Transmission-Level Applications of BESS

- **Firms solar power output** by smoothing variability and delivering predictable, dispatchable energy
- **Reduces renewable energy curtailment** by storing excess solar generation and supplying it during peak demand.
- **Provides ancillary services**, including frequency regulation, voltage support, spinning reserve, and black start capability.
- **Supports transmission network operation** by relieving congestion, reducing peak loading, and deferring infrastructure upgrades.
- **Enhances grid reliability and flexibility**, enabling higher penetration of utility-scale renewable energy.

Utility-Scale and Transmission-Level Applications of BESS



- It shows how the output profile of solar + battery system might behave on a summer’s day, with the net asset providing 100MW to the grid for 24-hours.

https://thundersaidenergy.com/downloads/solarbattery-co-deployments-output-profiles/

Regional Case Studies and Lessons for SAARC

Country	Project / Initiative	Key Highlights	Key Lesson
India	VGF Scheme for Standalone BESS (2023)	Government support for 4,000 MWh of standalone BESS through competitive bidding.	Financial incentives accelerate large-scale BESS deployment.
Sri Lanka	ADB Renewable Energy Integration Roadmap	BESS identified as a key technology for integrating solar and wind while improving grid flexibility.	Storage enables higher renewable penetration and grid stability.
Pakistan	ADB Grid-Integrated BESS Project	Planned 1,000 MW / 2,000 MWh transmission-connected BESS to strengthen the national grid.	Utility-scale BESS improves grid reliability and renewable integration.

Policy Enablers for BESS Deployment

- **Supportive tariff structures** (Time-of-Use tariffs, demand charges, energy arbitrage).
- **Financial incentives**, including subsidies, tax credits, and **Viability Gap Funding (VGF)**.
- **National energy storage targets and deployment mandates** to accelerate market adoption.
- **Clear interconnection standards and streamlined permitting** for faster project deployment.
- **Competitive procurement mechanisms** and market frameworks that recognize the value of BESS and ancillary services.

From Challenges to Opportunities: Enabling BESS Deployment

Challenges	➜ Enabling Actions	➜ Opportunities
High upfront capital cost	Financial incentives, VGF & green financing	Increased BESS investment
Battery degradation	Advanced battery management & recycling	Longer battery lifetime
Regulatory uncertainty	Clear policies & market mechanisms	Improved bankability
Data gaps	Better forecasting & digital planning	Optimal sizing & placement
Limited local manufacturing	R&D support & industrial incentives	Jobs, innovation & economic growth

Conclusions and Recommendations

- **Integrate BESS with solar energy planning** to improve grid reliability, flexibility, and renewable energy utilization.
- **Optimize battery size and placement** using techno-economic and data-driven planning approaches.
- **Strengthen policy and regulatory frameworks** to encourage investment and accelerate BESS deployment.
- **Promote grid modernization, digitalization, and regional collaboration** to support large-scale renewable integration.
- **Invest in research, local manufacturing, and workforce development** to build a sustainable BESS ecosystem in the SAARC region.

Thank You Very Much!