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Large-Scale Integration of Variable Renewable Energy: Key Issues and Emerging Trends

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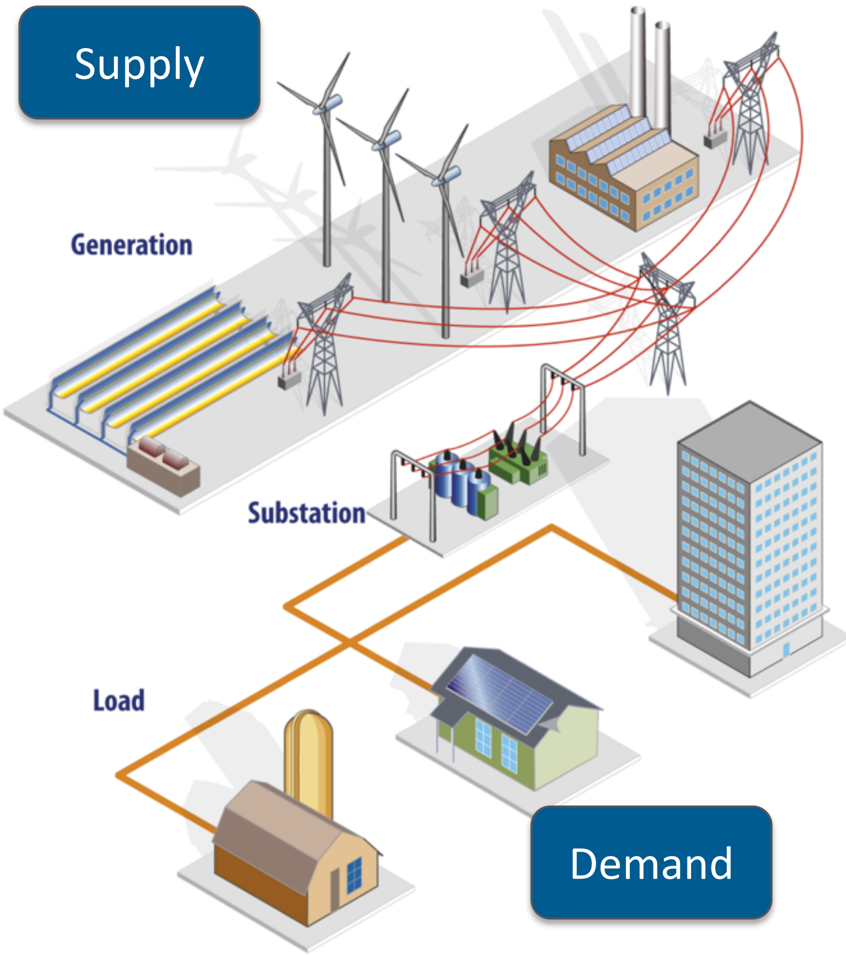
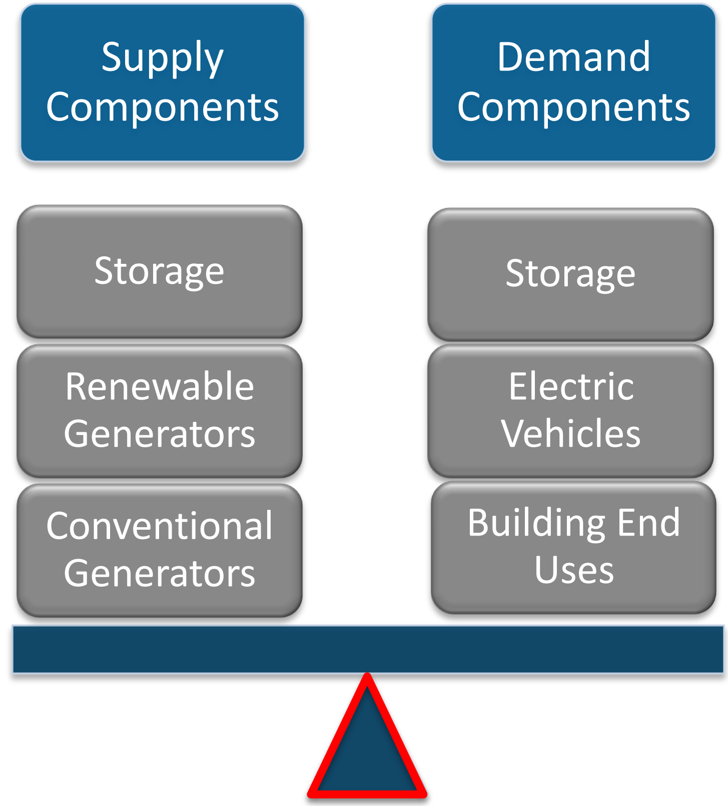
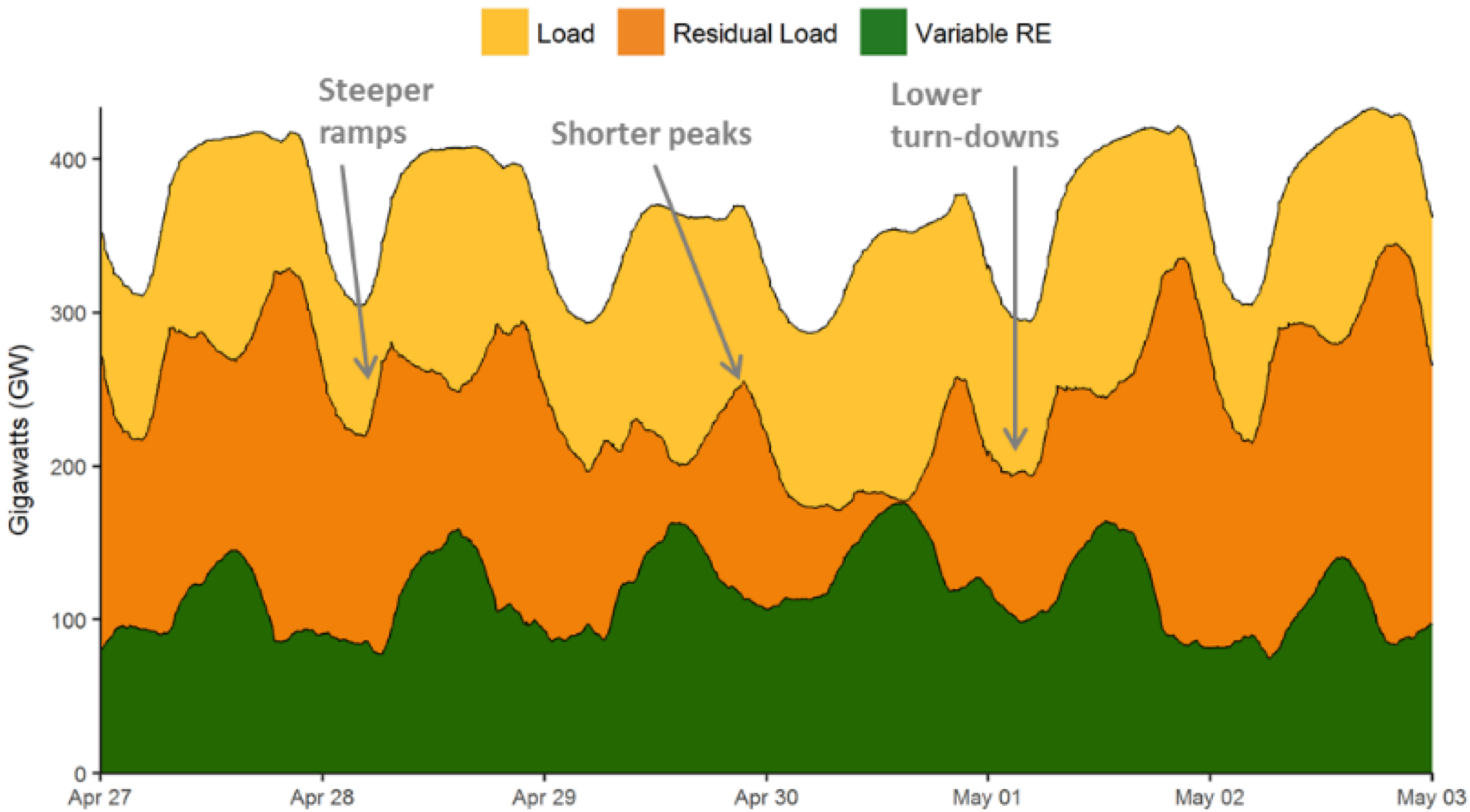
Grid Operations: A Matter of Balance





Supply and demand are both variable. The power system keeps these in balance at all times.

Wind and Solar Add Variability to Supply Side

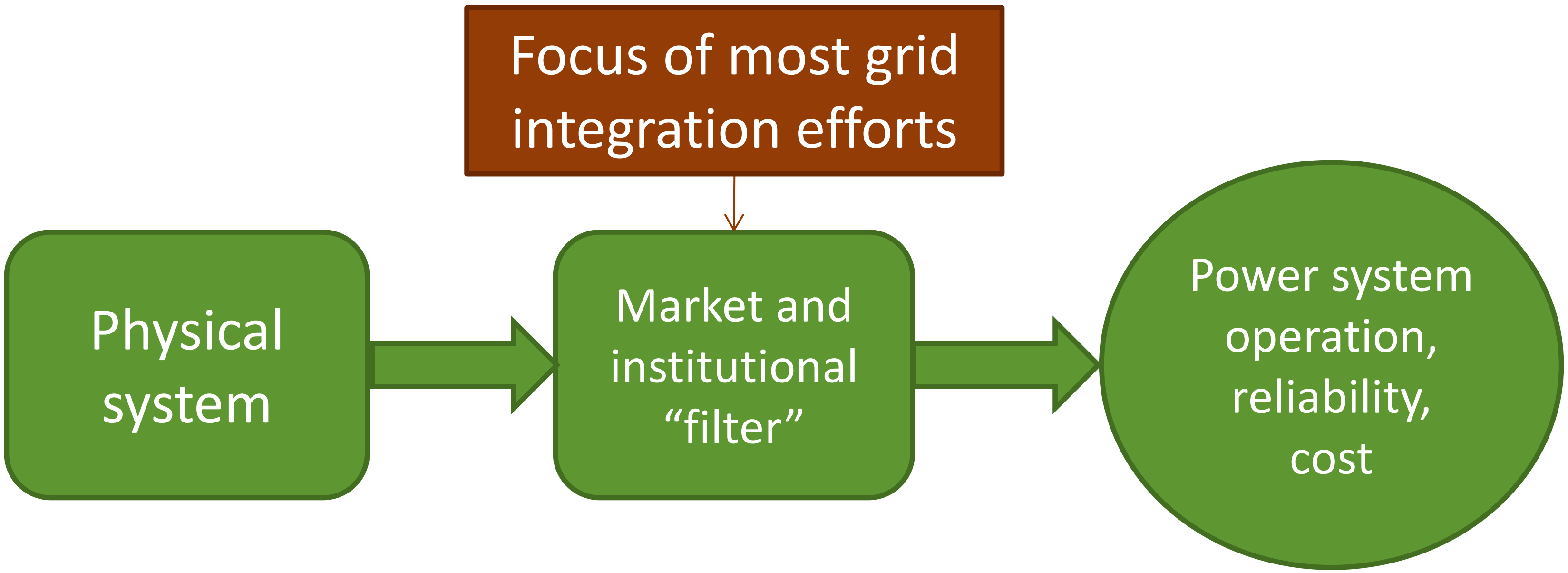


Flexibility: The ability of a power system to respond to change in demand and supply

Source: NREL Report No. FS-6A20-63039

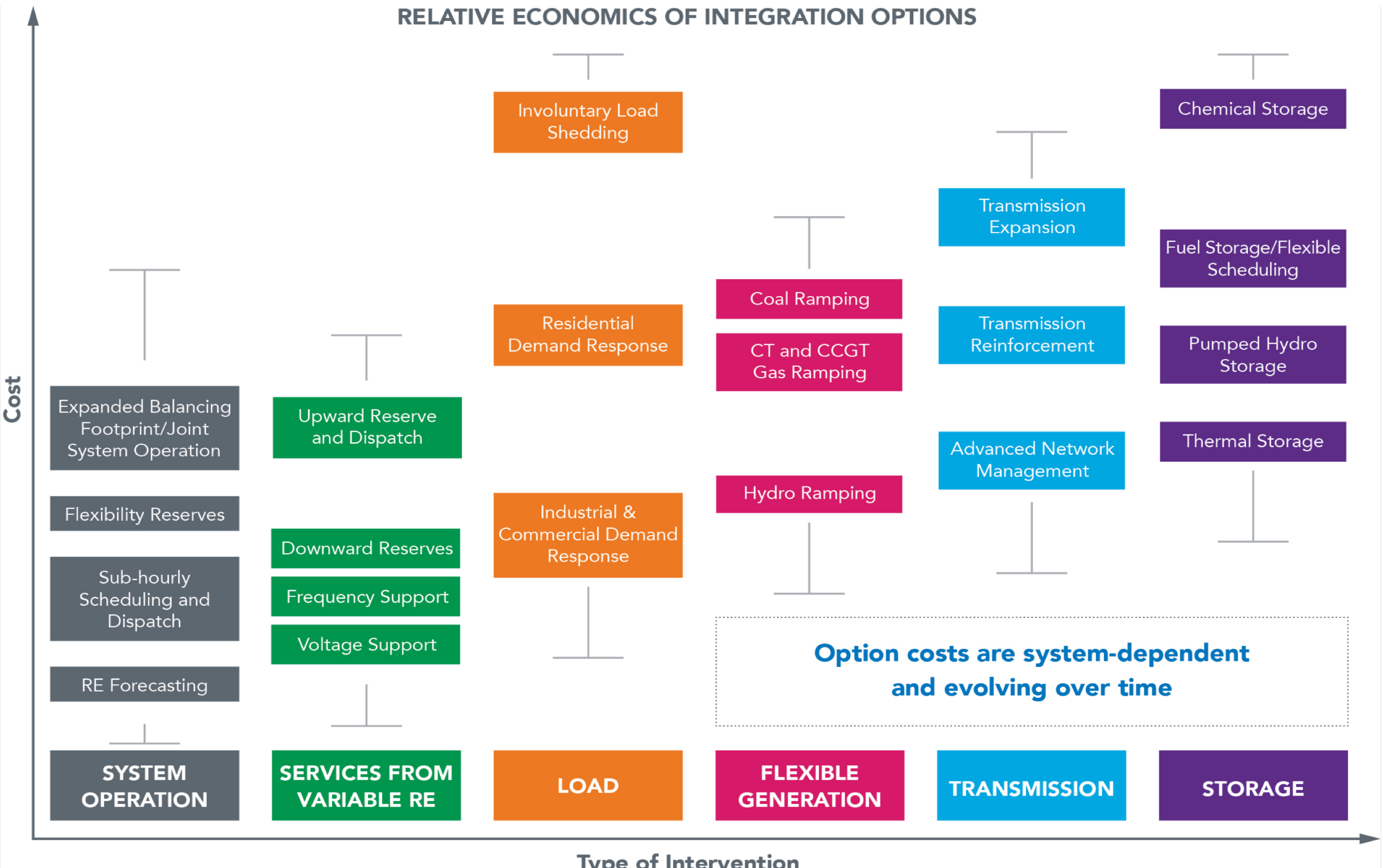
Accessing Flexibility Is A Key Objective For RE Grid Integration

- Physical power system: generators, transmission, storage, interconnection
- Institutional system: operations (e.g., scheduling, dispatch, forecasting), market rules, collaboration with neighbors



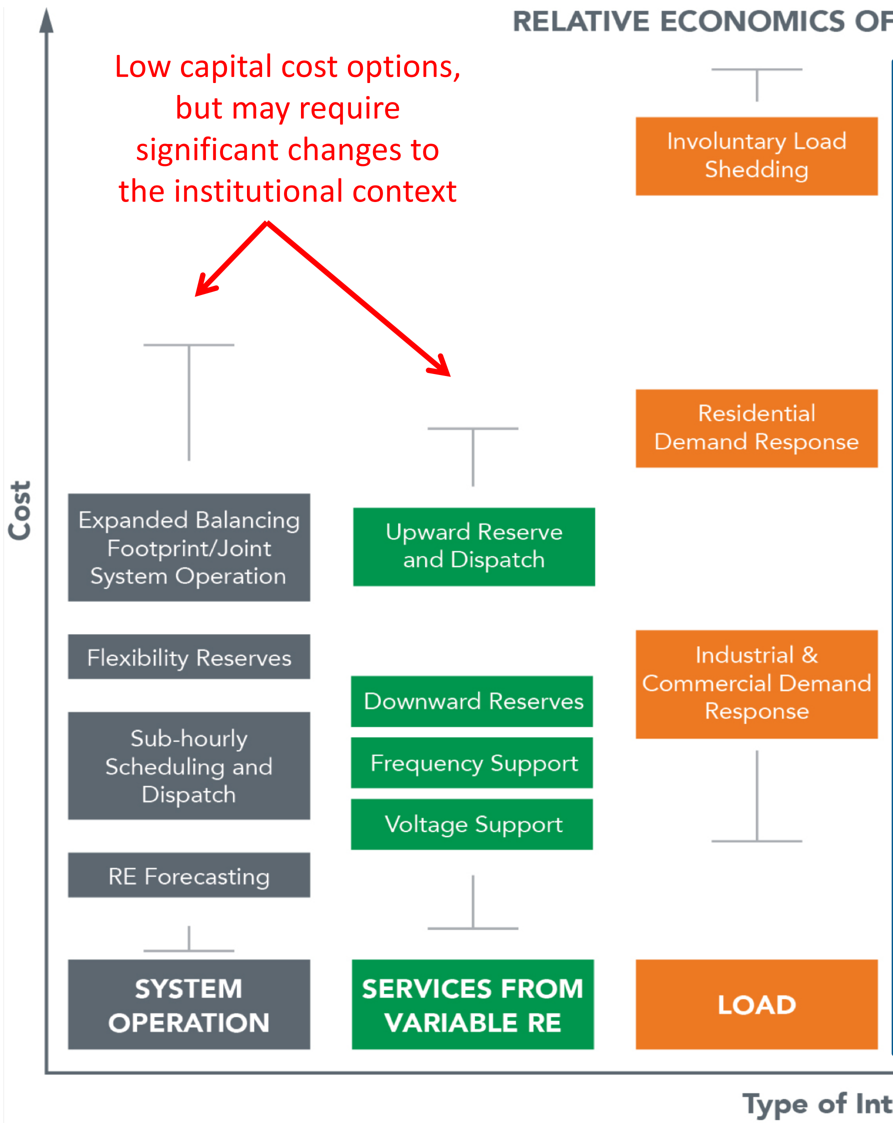
Power system operation (and grid integration!) relies on both

Frequently Used Options to Increase Flexibility



Source: Cochran et al. (2014). Flexibility in 21st Century Power Systems.

Frequently Used Options to Increase Flexibility

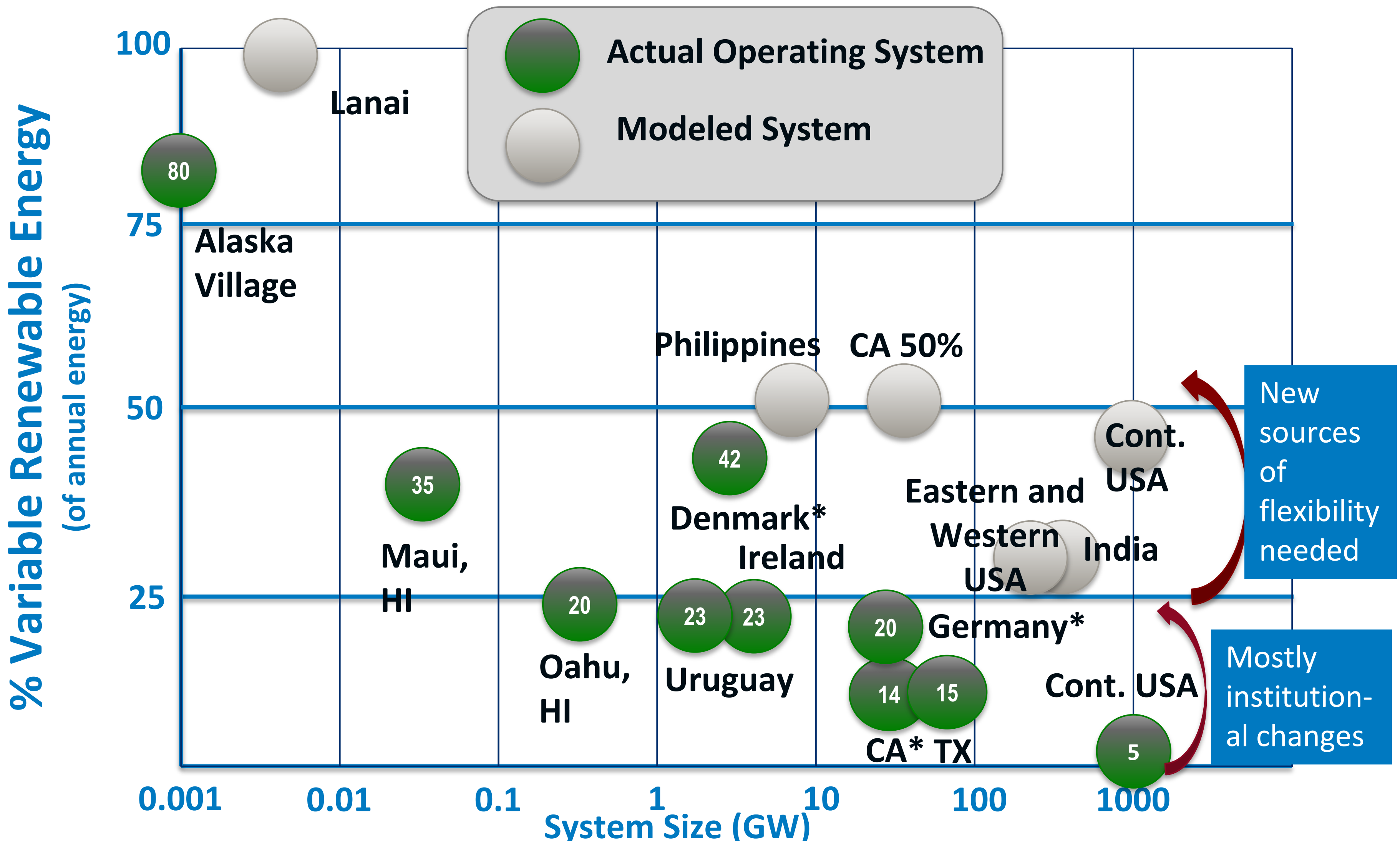


- Numerous options for increasing flexibility are available in any power system.
- Flexibility reflects not just physical systems, but also **institutional frameworks**.
- The costs of flexibility options vary, but institutional changes may be among the least expensive.
- Flexibility options frequently contribute to power system modernization, regardless of RE penetration levels.

Source: Cochran et al. (2014). Flexibility in 21st Century Power Systems.

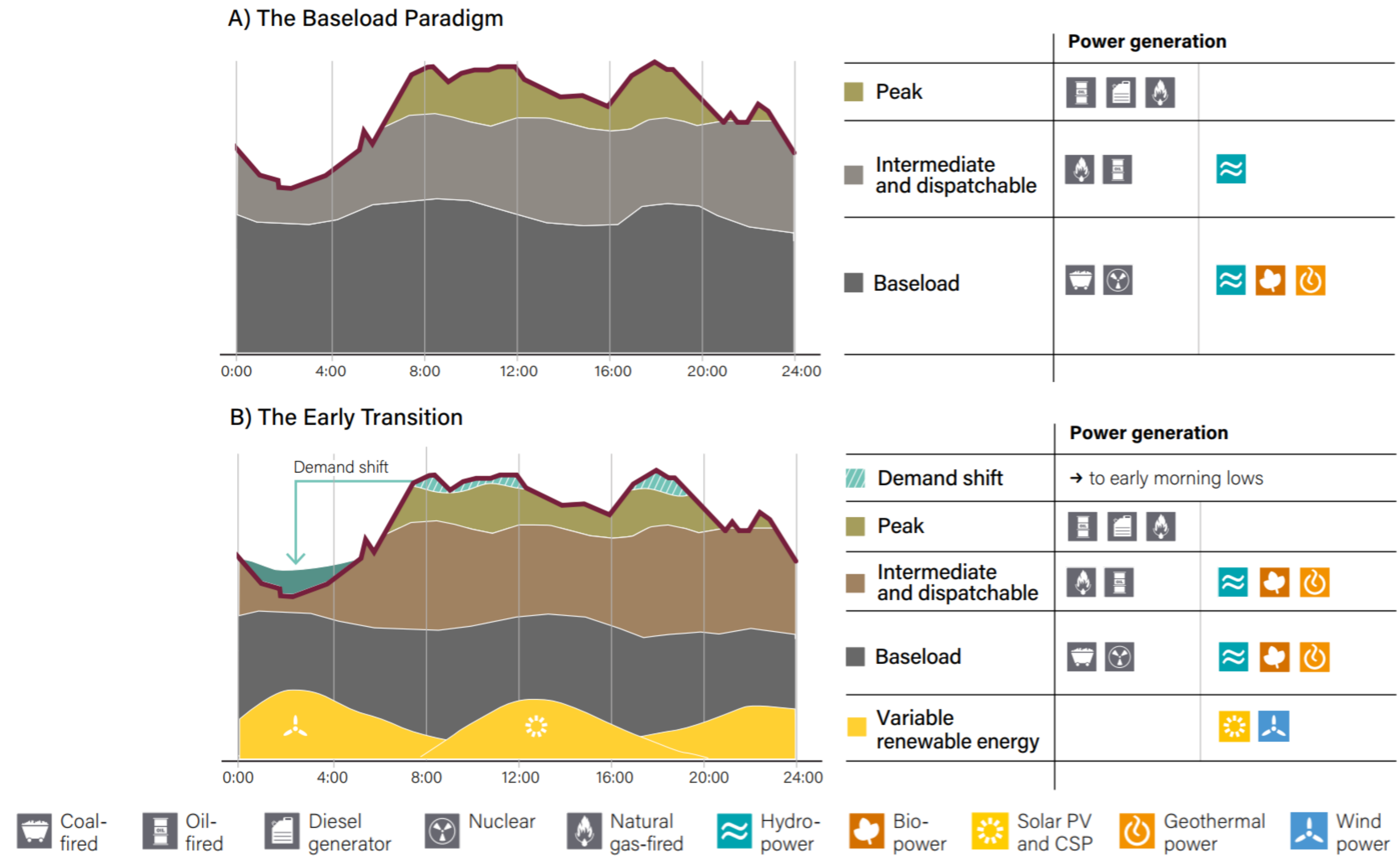
Frequently Asked Questions

Can Grids Support High Levels (>10-20% annually) of Variable RE?



* Part of a larger synchronous AC power system

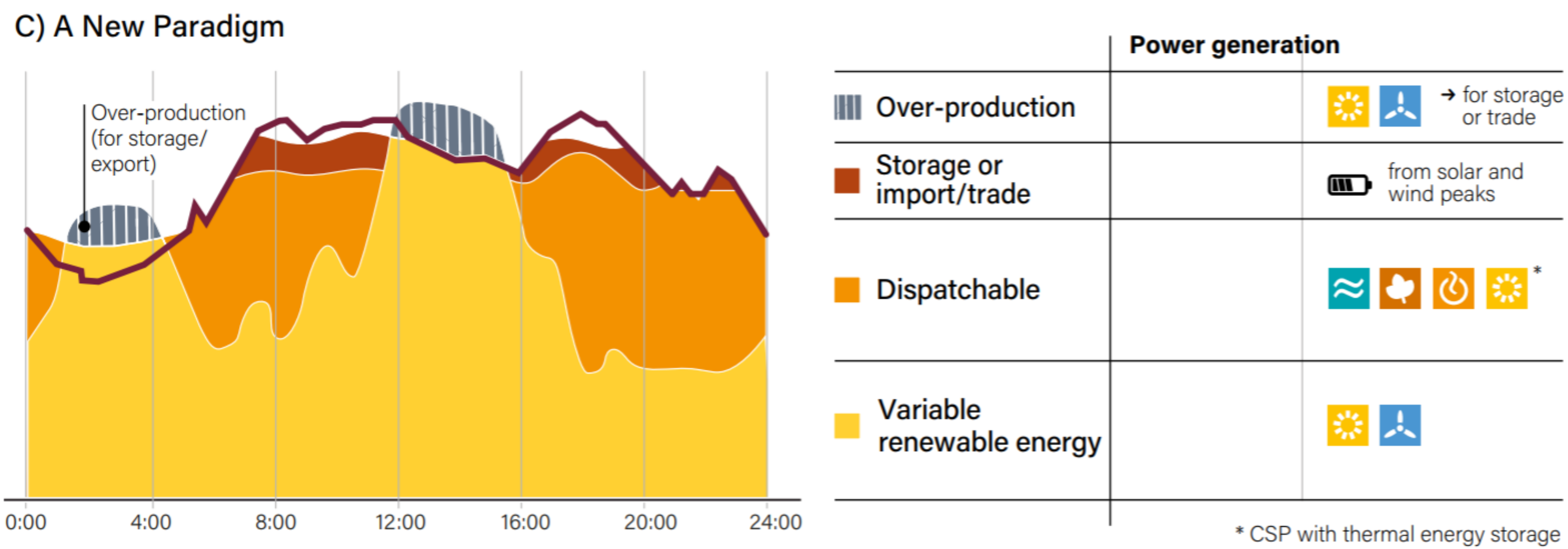
Can Variable RE Provide Baseload Power?



Source: REN21 2017

Can Variable RE Provide Baseload Power?

- Yes, variable RE can contribute to resource adequacy, but changes how we think of “baseload”
- In high RE systems, the balance of generation needs to be flexible to accommodate lowest marginal cost resources, and <u>not necessarily</u> be designed to run like a traditional baseload unit



Trend Is To Treat RE Like Conventional Power Plant

- **RE** as a good grid citizen
  - Visible
  - Schedulable
  - Dispatchable
  - Curtailable
  - Able to provide ancillary services

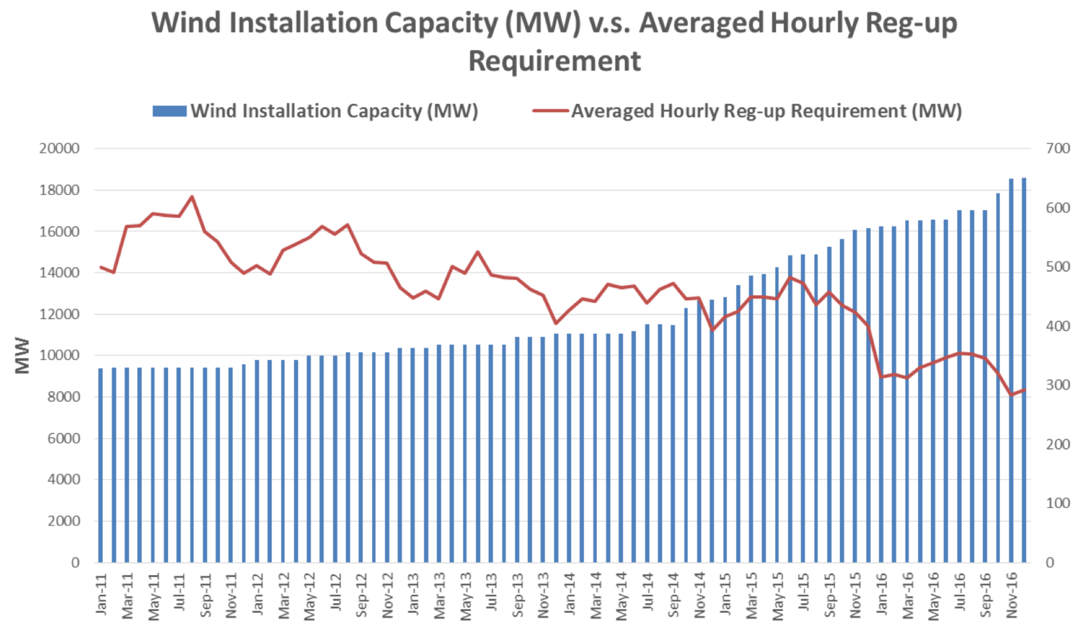
- Control technologies for wind and solar are now reflected in PPAs and grid codes

- Instead of priority dispatch, address RE financing concerns separately from system operations

ercot

Do Individual Renewable Energy Plants Require Backup By Conventional Plants?

- <u>Individual</u> plants do not require backup
  - Reserves are optimized at system level.
- Wind and solar could increase need for operating reserves.
  - But this reserve can usually be provided from other generation that has turned down
  - This reserve is not a constant amount (depends on what wind/solar are doing)
  - Many techniques
  - are available to reduce needed reserves.



Source: Electricity Reliability Council of Texas

- Wind and solar can also provide reserves; in both directions when curtailed

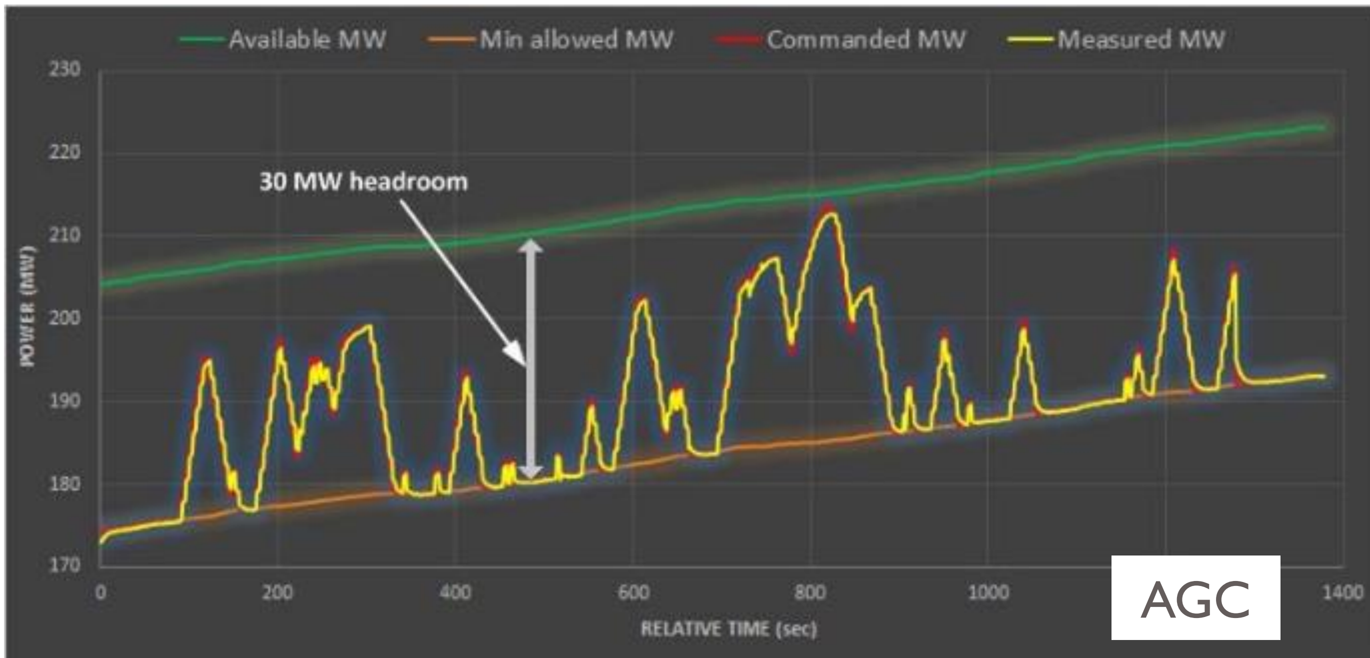
Wind And Solar Can Provide Reserves and Flexibility

Timescale of flexibility	Type of flexibility	How variable RE provides this
Sub-second	Autonomously generated: synthetic inertia	Fast frequency response with a power electronic converter
Seconds	Autonomously generated: synthetic governor response	Slower frequency response through electronic governor
Minutes	Remotely operated: automatic generation control (AGC)	Market or system operator inclusion in ancillary services
Minutes to hour	Economic dispatch	Market or system operator inclusion in dispatch
Day	Scheduling (unit commitment)	Market or system operator inclusion in day-ahead scheduling

Source: Jacobs et al, 2016

Large-Scale Solar PV Plant Regulation

NREL/FirstSolar/California Independent System Operator experiment: 300 MW plant following automatic generation control (AGC) signal



We demonstrated that PV plants (and wind power plants) can deliver essential grid services.

Powered by SunShot
U.S. Department of Energy

Loutan, C. et al. (2017). Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant. NREL/TP-5D00-67799.

Does variable RE generation require storage?

Storage is always useful, but may not be economic.

- Detailed simulations of power system operation find no need for electric storage up to 30% wind penetration (WWSIS, CAISO, PJM, EWITS).

Source: Sandia National Laboratories

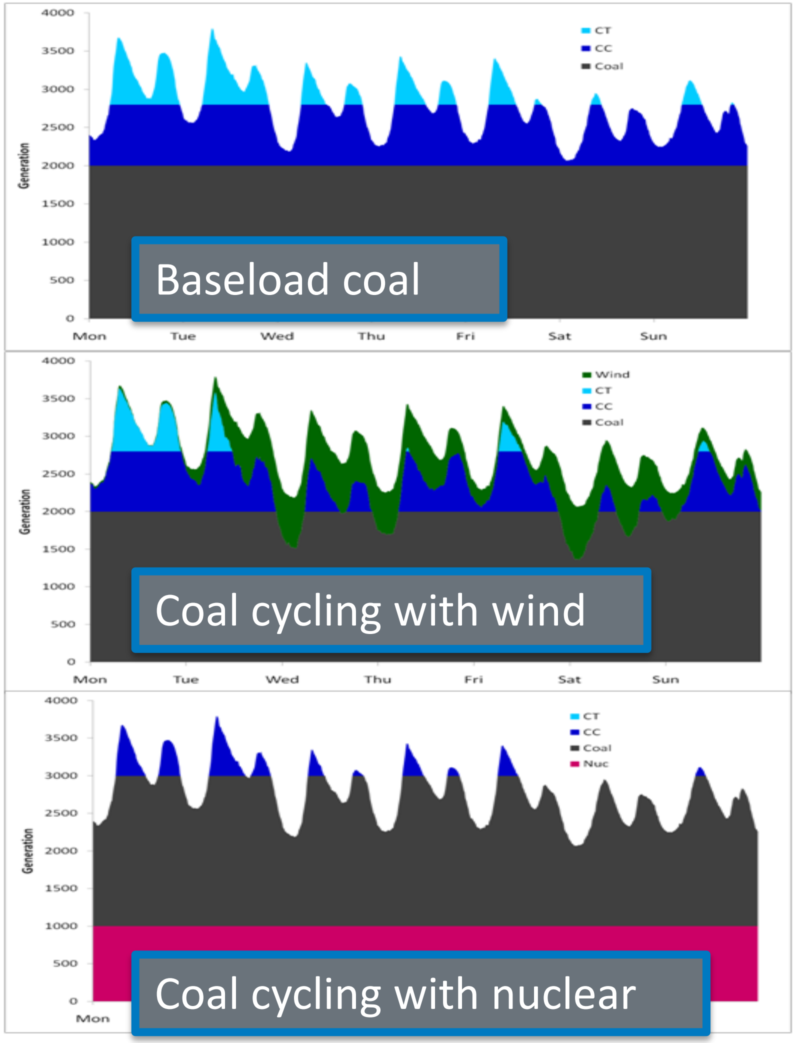
- 50% wind/solar penetration study in Minnesota found no need for storage (MRITS, 2014)

- At higher penetration levels, storage could be of value.
  - Recent NREL Low Carbon Grid Study finds storage provides needed flexibility at very high RE penetrations

How Expensive Is Integrating Variable Renewable Energy Generation To The Grid?

All generation (and load) has an integration cost:

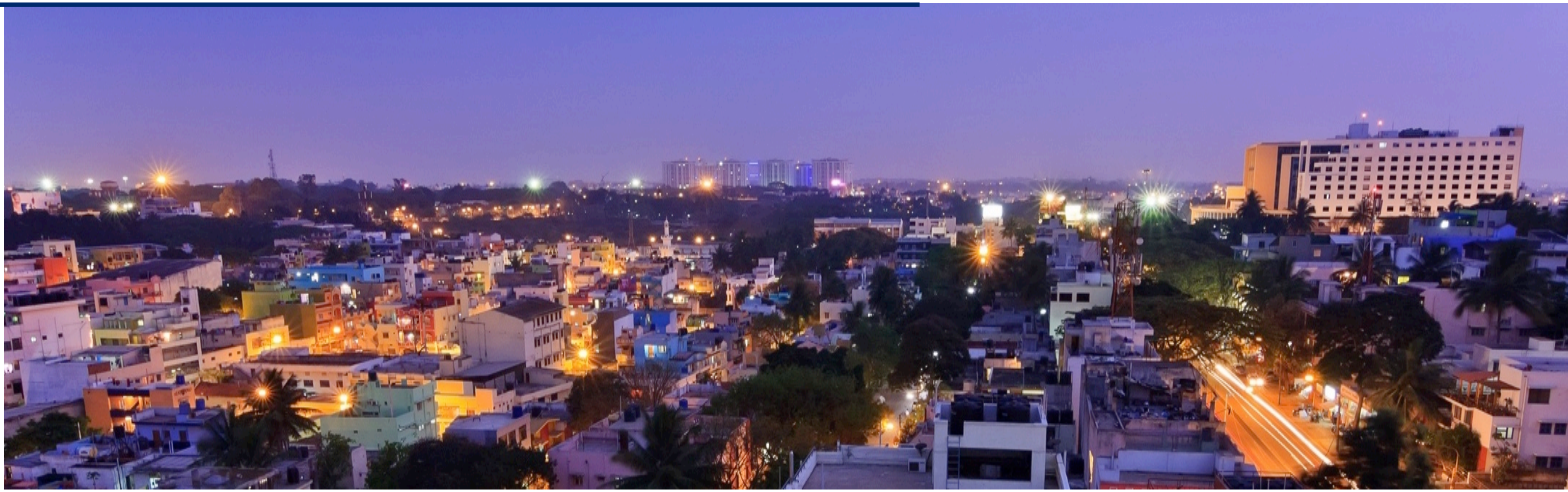
- Any generator can increase cycling for remaining generation
- Conventional plants can impose variability and uncertainty costs
- Conventional plants can create conditions that increase need for system flexibility
  - Must-run hydropower and IPP contracts; thermal plants that cannot be turned down
  - Start-up times for coal require day-ahead scheduling, which is harder for wind



http://www.nrel.gov/docs/fy11osti/51860.pdf

Analyzing Grid Integration Challenges and Solutions: India Case Study

Grid Integration Studies: Our Purpose



- As India develops 100 GW of solar and 60 GW of wind energy, how would the system operate in 2022?
- What can policy makers do to lower the cost of operating this system and better integrate RE?
  - Note: Fixed costs considered as sunk cost

Methodology

Build an operations model of today's power system

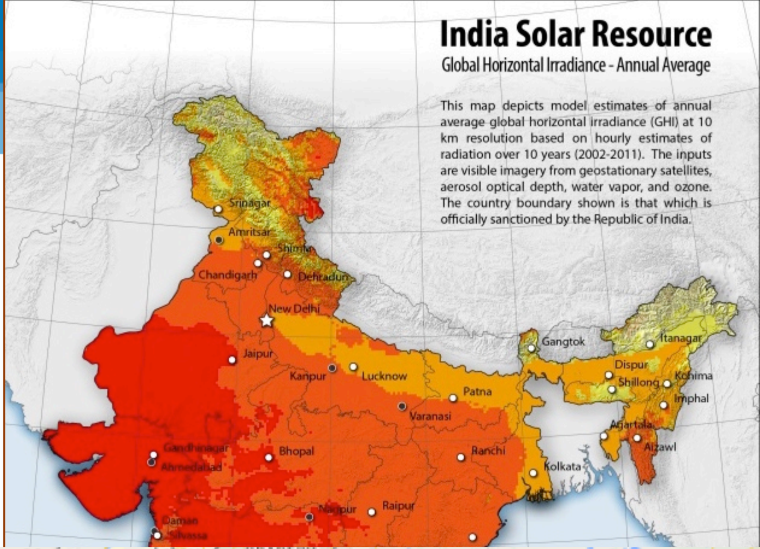
For future year, forecast load and necessary capacity to meet load

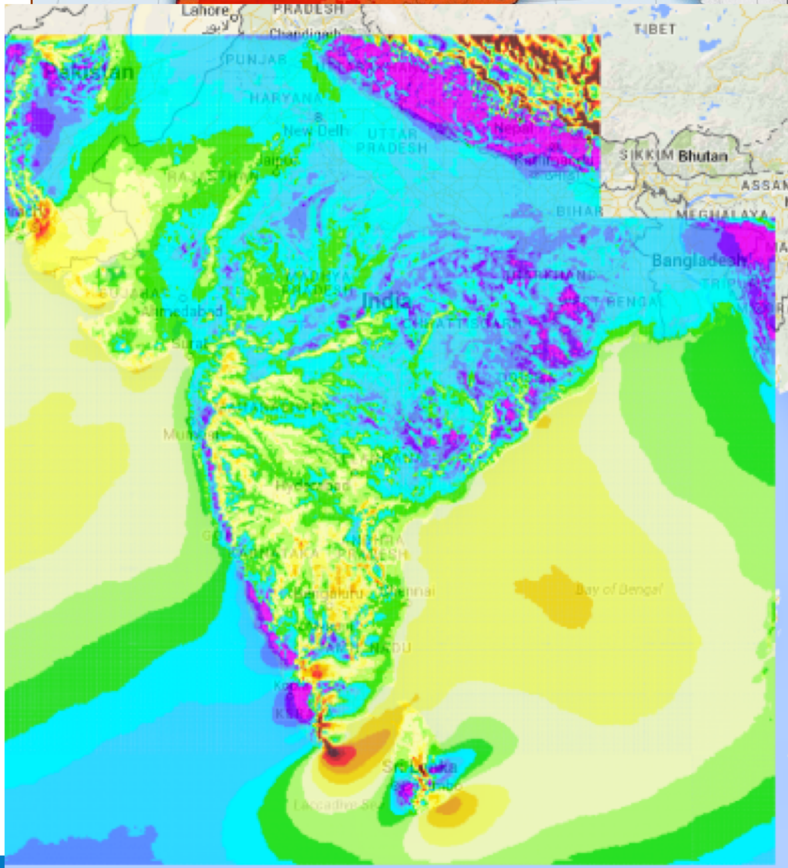
Simulate power system operations in the future year

NREL frequently uses a production cost model to conduct this type of analysis

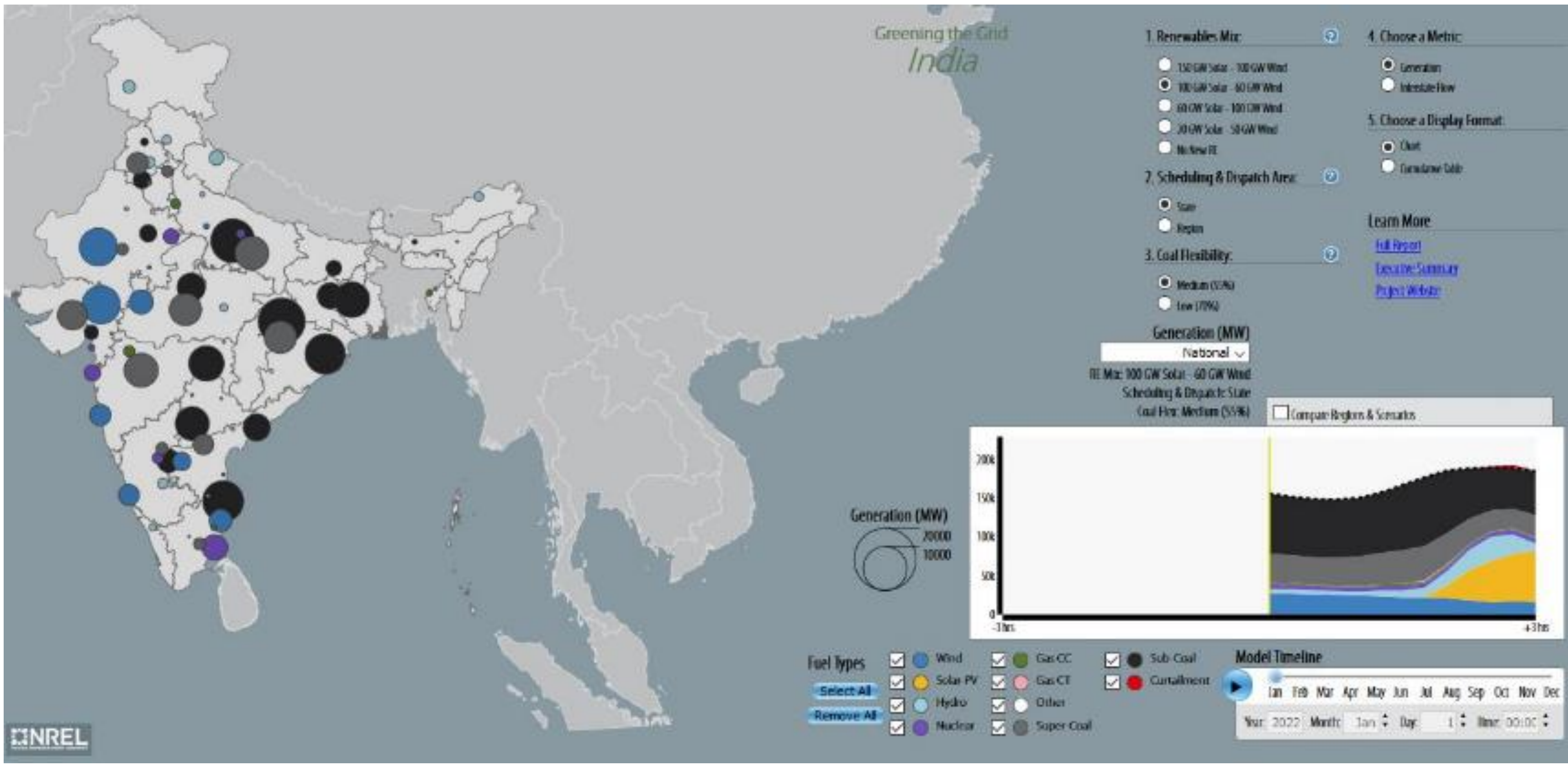
Modeling Features

- High-resolution wind and solar resource data (both forecasts and actuals)
  - Wind: 5-minute weather profiles for each 3 x 3 km^2 area
  - Solar: 1-hour weather profiles for each 10 x 10 km^2 area, including impact of aerosols
- Unique properties for each generator
- Enforced state-to-state transmission flows
- Interregional transmission limits that adhere to reliability standards



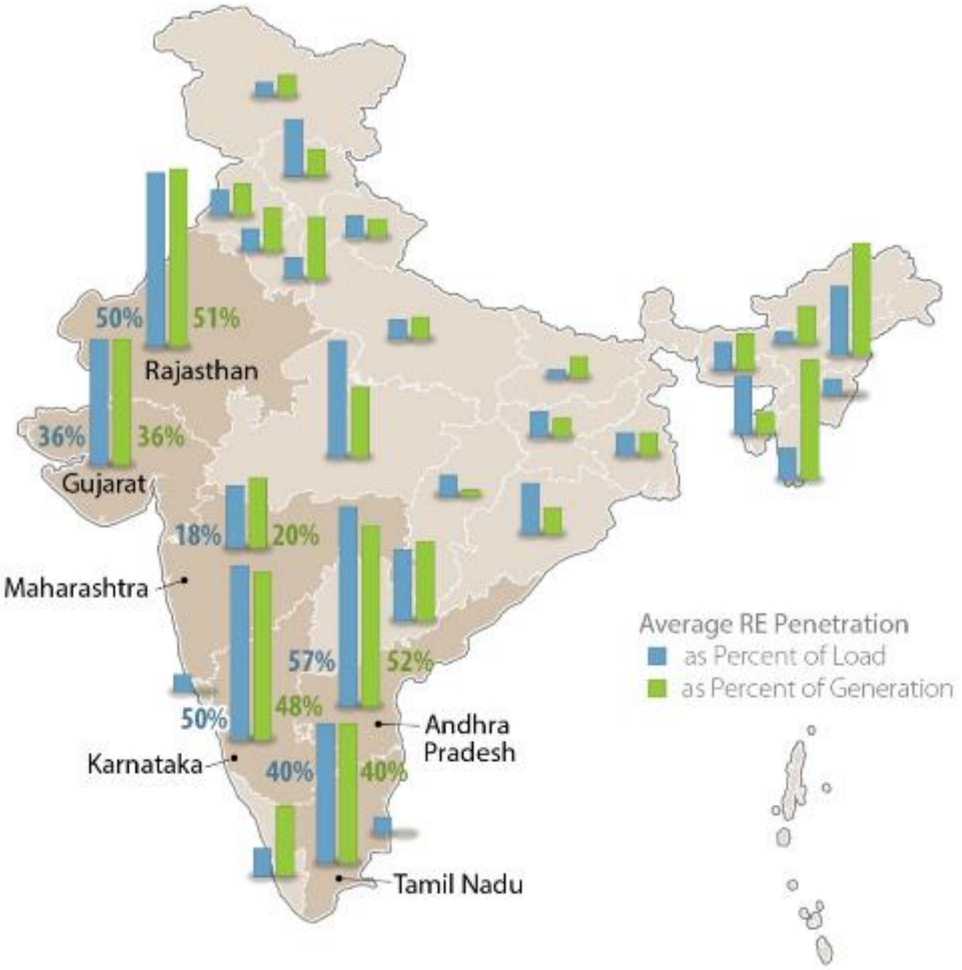


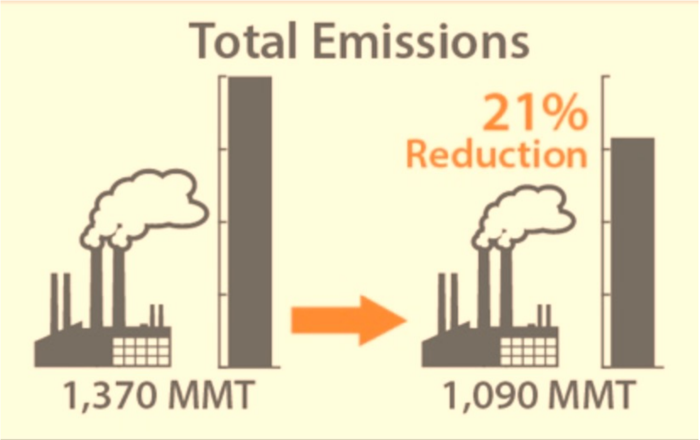
India’s Power System in 2022—Achieving System Balance Every 15 Minutes



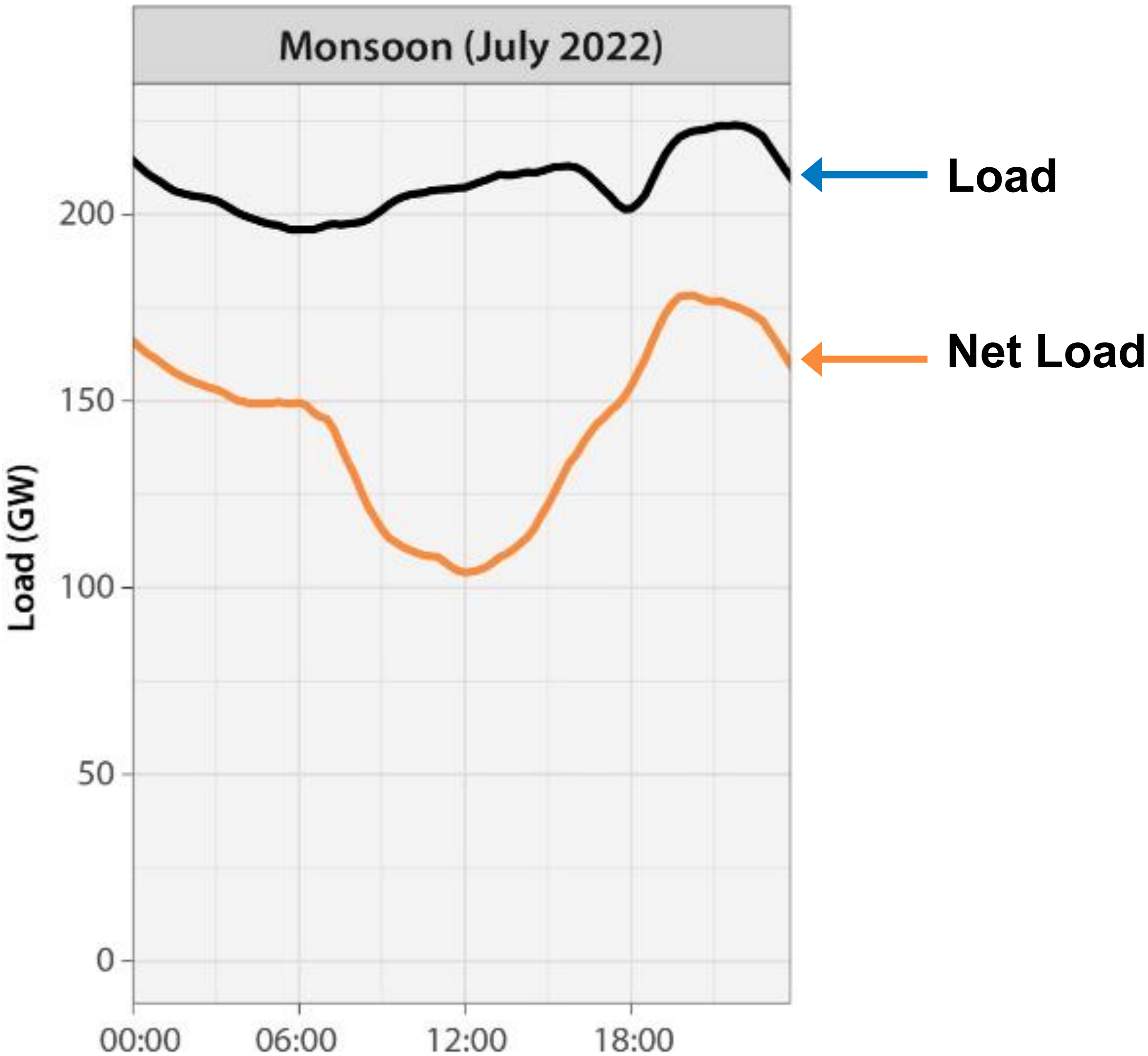
http://www.nrel.gov/india-grid-integration

Annual Impacts: 175 GW RE Can Meet 22% of India's Annual Electricity Demand with Minimal RE Curtailment





Daily Impacts: Existing Flexibility in the Coal-Dominated System Can Manage RE Variability



Retiring 46 GW of Coal (20% of Coal Capacity) May Not Negatively Affect Operations

Change in coal plant load factors after 46 GW of coal plants are retired

Each dot represents one unit

46 GW coal (205 units) operate very little in a high-RE future

A system with 175 GW of RE could support some combination of higher demand growth or retirements of generation

Strategies for Better Operation Can Reduce the Cost of RE Integration and Reduce Curtailment

Coordinated operations across states

Cost savings

State
Scheduling and dispatch

USD 980 million annually

Regional
Scheduling and dispatch

As operated in 2014

Lower technical minimums for coal plants

RE curtailment

70%
Technical minimum

3.5%

1.4%

55%
Technical minimum

Batteries Do Not Add Value to RE Integration from a Scheduling/Dispatch Perspective

- 2.5 GW batteries reduce RE curtailment and peak coal consumption
- But batteries charge during the day, in part on coal, and have efficiency losses
- Electricity savings from reduced RE curtailment (1.2 TWh) is offset by battery efficiency losses (2.0 TWh)
- Total coal generation is not affected
- CO2 emissions do not decline
- **Batteries provide value for other reasons outside scope of study:**
  - Local transmission congestion, ancillary services…

BATTERY STORAGE

100 GW SOLAR, 60 GW WIND

NORMAL OPERATIONS (NO BATTERY STORAGE)	2.5 GW BATTERY STORAGE
230,000 INR Crore Annual Production Cost	**0.33%** Savings annually
1.4% Renewable Energy Curtailment	**1.1%** Renewable Energy Curtailment

Summary and Takeaways

- Flexibility is a prized quality of power systems with increasing levels of variable renewable energy generation

- The "flexibility supply curve" is different in every power system, but often most the cost effective changes to the power system are institutional (changes to system operations, contracts, and market designs)

- Modern utility-scale solar and wind generators are capable of providing a variety of grid services… However, institutional measures need to be in place (preferably from the inception of the project) to ensure these capabilities are present and accessible to the system operator.

NREL/PIX 10926

Contacts and Additional Information

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Greening the Grid

greeningthegrid.org

India Integration Study

https://www.nrel.gov/analysis/india-renewable-integration-study.html

Questions & Discussion

Discussion

- What are your goals for wind and solar? What is the motivation behind these goals?
- Are there any specific operational or technical challenges you are facing now? Any challenges you anticipate at higher penetrations?
- Are there specific initiatives we should be aware of that are dedicated to or in alignment with these goals and challenges?

Topics for Collaboration

Smaller, near-term efforts	• Best practices in systems/capacity expansion planning or • Best practices in assessing system stability/ancillary services approaches under increasing VRE • Conduct a data inventory to identify gaps that might affect a larger grid study
Larger, long-term efforts	• Conducting a national VRE penetration study • Conducting road-mapping • Coordinate in some way with IEA with their Clean Energy Transitions Initiative