India RE Grid Integration Study

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21st Century
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Accelerating the transformation of power systems

WORLD BANK GROUP

ESMAP
Energy Sector Management Assistance Program

Core modeling team: POSOCO, NREL, LBNL

Broader modeling team: Central Electricity Authority, POWERGRID, and state load dispatch centers in Maharashtra, Gujarat, Tamil Nadu, Karnataka, Rajasthan, and Andhra Pradesh

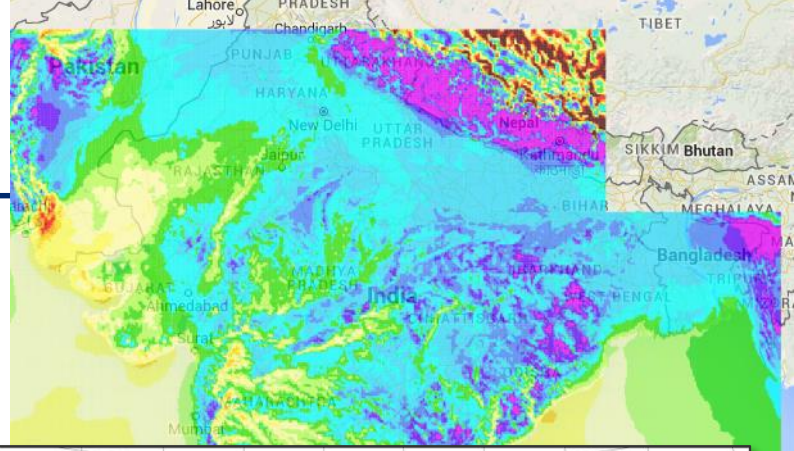
Grid Integration Review Committee: Over 150 experts from India; 12 meetings total

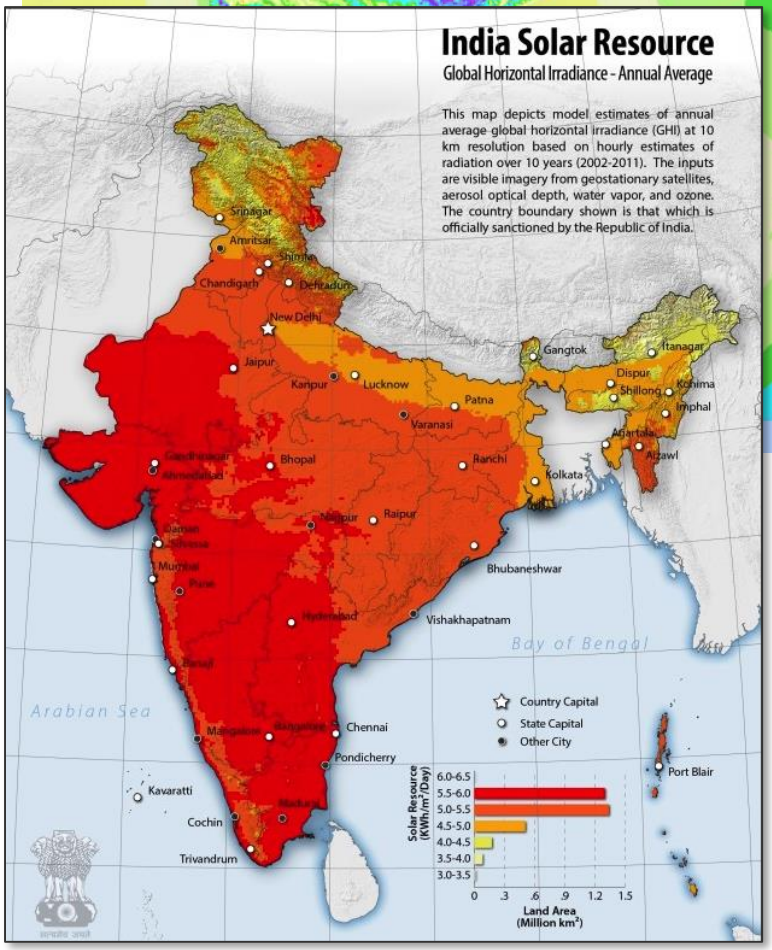
Grid Integration Studies: Our Purpose

- If 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

Modeling features

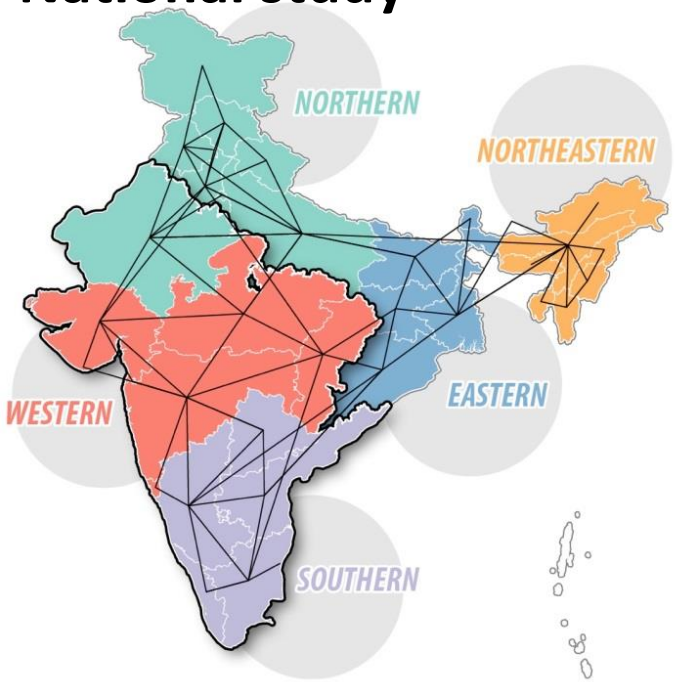
- High-resolution wind and solar resource data (both forecasts and actuals)
  - Wind: 5-minute weather profiles for each 3 x 3 km^2 area
  - Solar: 1-hour weather profiles for each 10 x 10 km^2 area, including impact of aerosols
- Unique properties for each generator
- CEA/CTU projections of properties and locations of new lines and power plants for 2022
- Enforced state-to-state transmission flows
- Interregional transmission limits that adhere to reliability standards





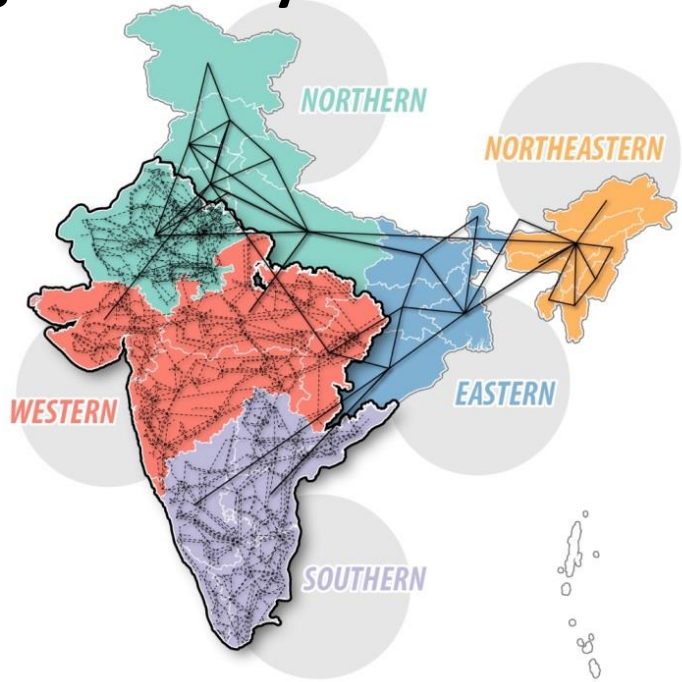
Transmission representation in the model

National study



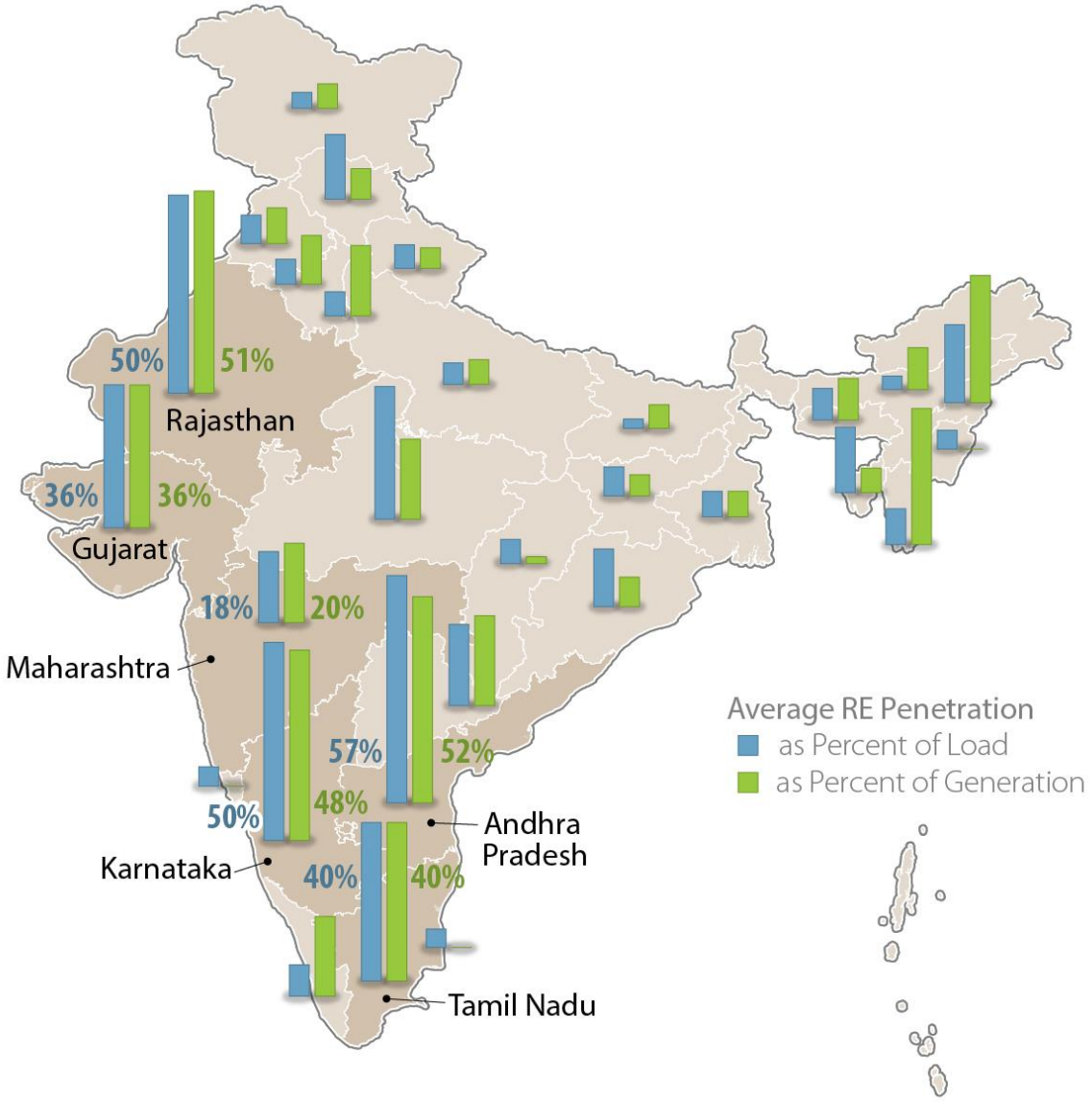
- All generation and transmission located on a single node per state plus union territories (36 nodes total)
- No enforced intrastate transmission constraints

Regional study

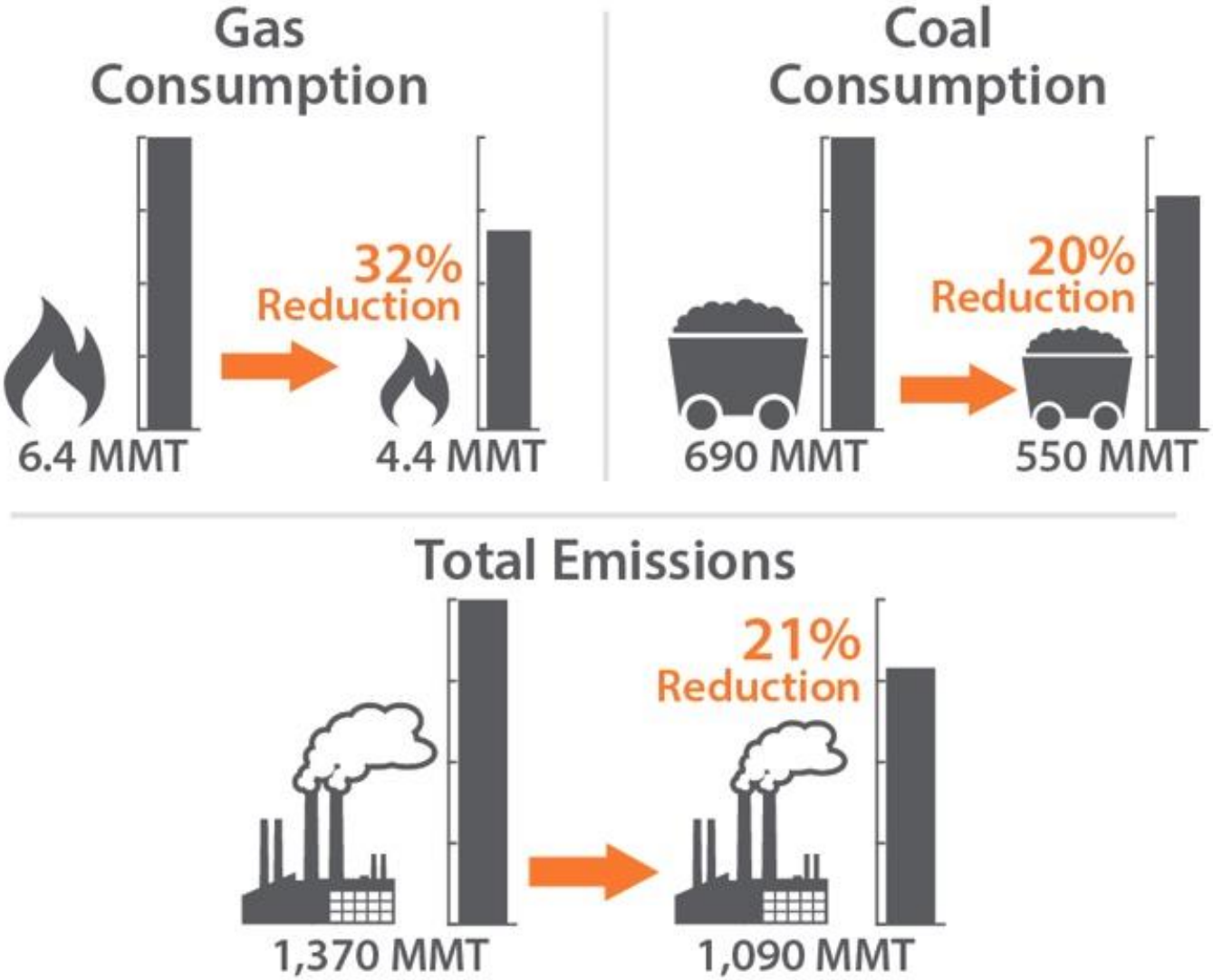


- Full, planned transmission system in Southern and Western Regions plus Rajasthan (3,280 nodes)
- Loading limits enforced on all relevant intrastate lines; congestion limits enforced on all high-volume intrastate lines (>400 kV)

Results: RE annual penetration is 22%, with an instantaneous peak of 54%



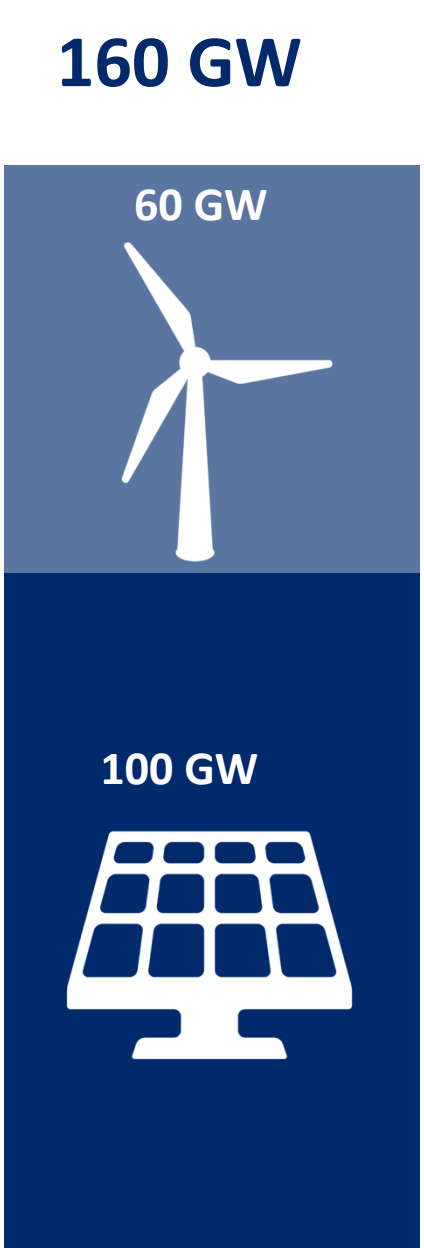
Fuel consumption reduction of 20% coal, 32% gas. Total CO_2 emissions reduction of 21%.



* MMT: million metric tonnes

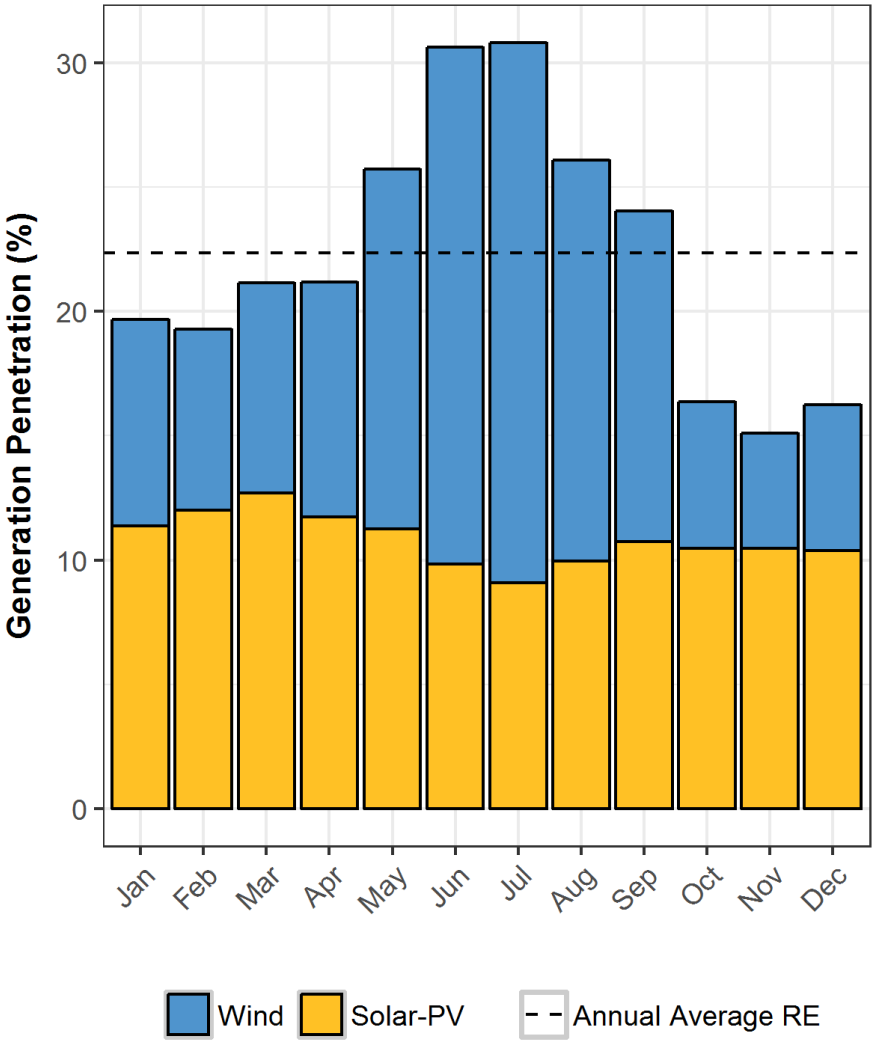
Key Finding #1: 160 GW wind & solar can be integrated to the grid with continued efforts to improve access to existing system flexibility

- Based on the fulfillment of current efforts to provide better access to the physical flexibility of the power system…
  - Power system balancing with 100 GW of solar and 60 GW of wind is achievable at 15-minute operational timescales with minimal RE curtailment
  - The system can handle forecast errors, net load changes, and exchanges of energy between regions
  - Physically, the system has the flexibility to manage; the challenge going forward is accessing this flexibility through appropriate regulations, operational rules, etc.

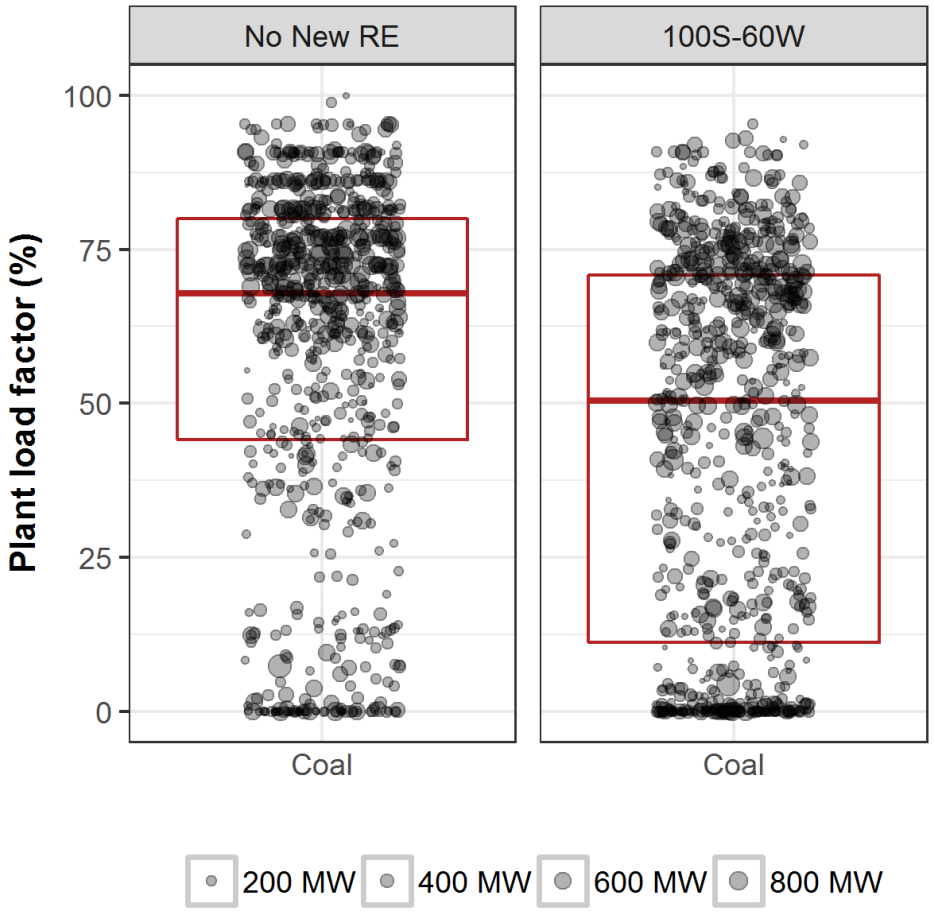


Key Finding #2: With effective state-level planning, curtailment may not be a barrier to RE investment

- Curtailment risk is a large concern to RE developers and investors
- Study finds curtailment averages only 1% nationally, based on no intrastate congestion
- Curtailment is highest in the southern region at roughly 3%



Key Finding #3: Average coal plant load factors fall 63% to 50%, with over 19 GW of capacity that never starts*



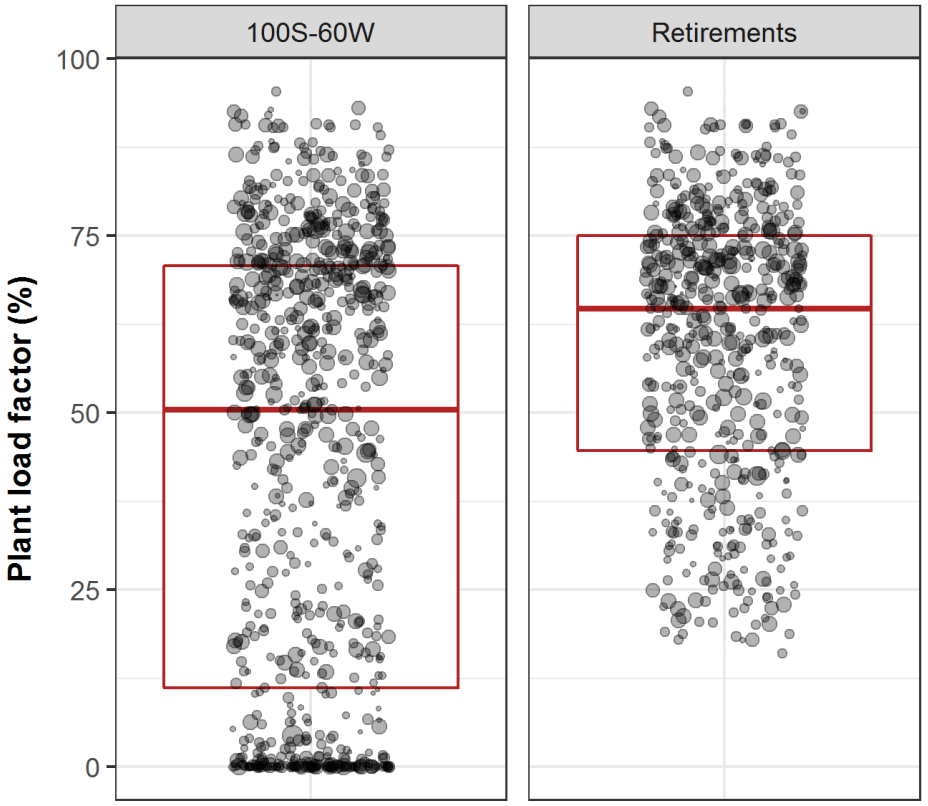
Coal capacity below 25%, and above 75% PLF

PLF	No New RE	100S-60W
<25% PLF	30 GW	61 GW
>75% PLF	92 GW	46 GW

* Compared to No New RE; Plant load factor (PLF) is calculated using weighted averages

Key Finding #4: Retiring 46 GW of coal does not adversely affect system flexibility

- 46 GW coal (205 plants) operate on average less than 15% capacity and contribute just 1% to annual coal generation
- System still operates effectively without these plants, based on adequate intrastate transmission
- Plant load factors of remaining plants increase from 50% to 62%



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

Key Finding #5: Changes to operations can reduce the cost of RE integration and reduce curtailment

Improved merit order dispatch and resource sharing across state and regional boundaries lower costs

- 2.8% annual savings from regional optimization
- Fewer coal plants need to run at part load
- More efficient use of coal plants means long-run investment costs likely lower with fewer coal plants needed

Lower turn-down plant levels biggest driver to reduce RE curtailment

- 70% = 3.5% RE curtailment
- 55% = 1.4%
- 40% = 0.76%

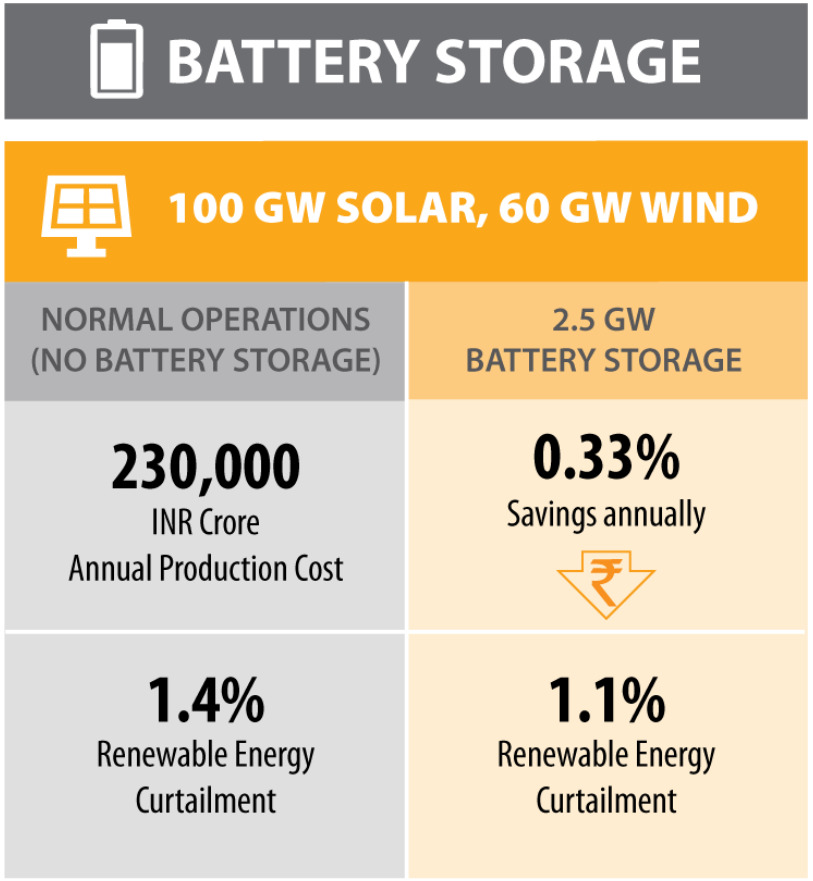
Other aspects of coal plant flexibility (e.g., ramp rates) and increased interregional transmission capacity are critical but changing these had small impact on system operations and RE integration

Key Finding #6: Batteries do not add value to RE integration from 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
- CO_2 emissions do not decline

Batteries could have value for other reasons outside scope of study:

- **Local transmission congestion, ancillary services…**



Thank you!

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