GREENING THE GRID

RE Grid Integration Study with India

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Sponsors and Official GOI Lead

GOVERNMENT OF INDIA
MINISTRY OF POWER

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21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

WORLD BANK GROUP

ESMAP
Energy Sector Management Assistance Program

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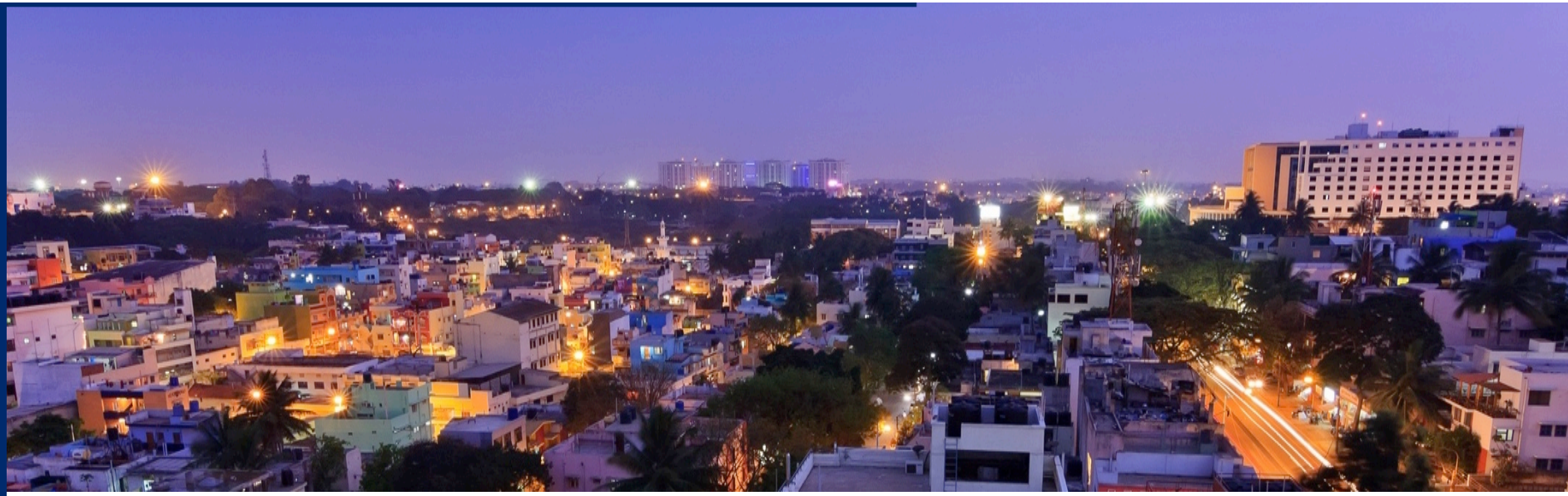
Grid Integration Studies: Our Purpose



- 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

Stakeholder Participation

- Grid Integration Review Committee
  - Peer Review and Guidance
  - Over 150 Experts
  - Four sets of meetings

	National (New Delhi)	Southern (Bengaluru)	Western (Mumbai)
1st GIRC	13/10/15	15/10/15	19/10/15
2nd GIRC	19/4/16	21/4/16	22/4/16
3rd GIRC	18/7/16	20/7/16	22/7/16
4th GIRC	17/2/17	20/2/17	22/2/17

More than 2000 person hours

Methodology Overview

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

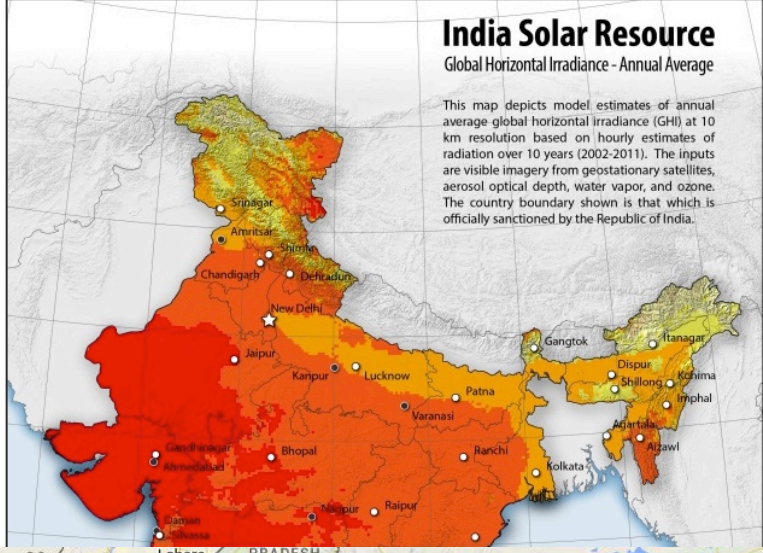
Greening the Grid uses the PLEXOS production cost model

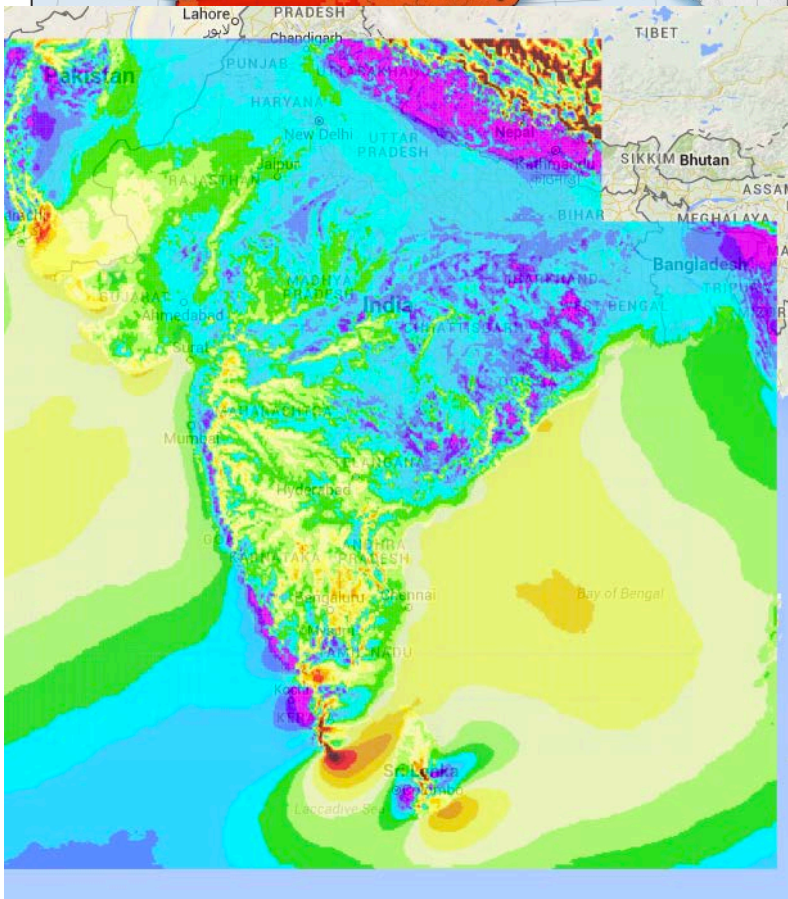
Studied scenarios

Scenario name	Solar (GW)	Wind (GW)	Description
No New RE	5	23	Wind and solar capacities installed as of 2016
20S-50W	20	50	Total installed capacity as targeted in Green Energy Corridors & National Solar Mission
100S-60W	100	60	Current Government of India target for 2022
60S-100W	60	100	Solar and wind targets reversed in comparison to official target
150S-100W	150	100	Ambitious RE growth

Modeling features

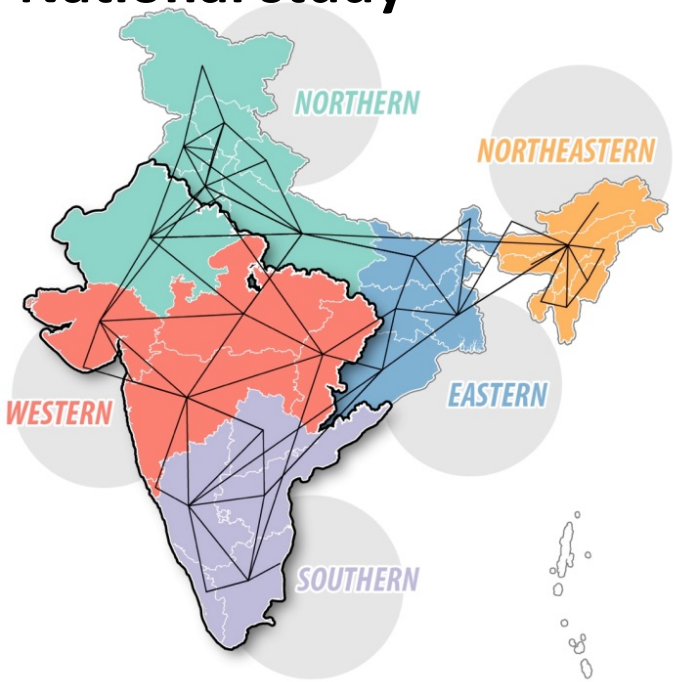
- High-resolution wind and solar resource data (both forecasts and actuals)
  - Wind: 5-minute weather profiles for each 3 x 3 km^2 area
  - Solar: 1-hour weather profiles for each 10 x 10 km^2 area, including impact of aerosols
- Unique properties for each generator
- CEA/CTU projections of properties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





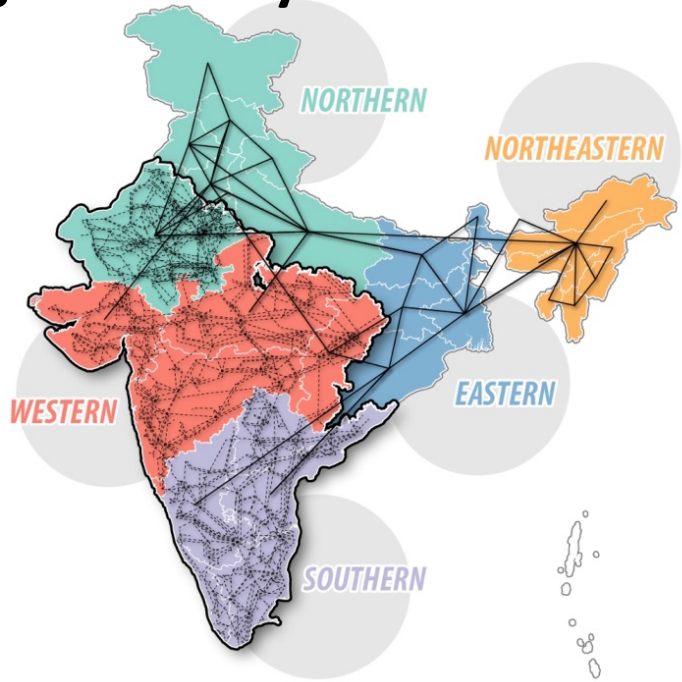
Transmission representation in the model

National study



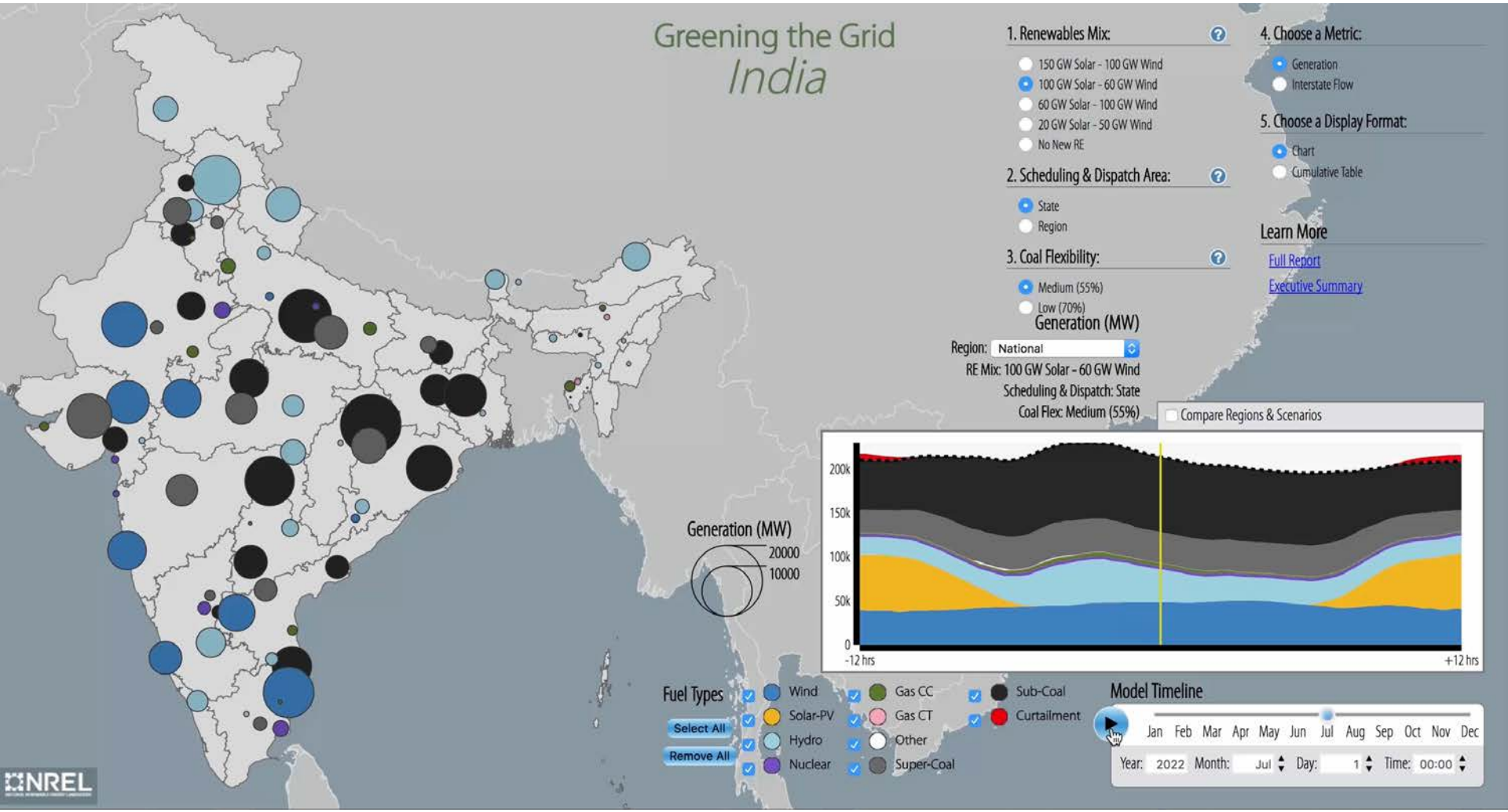
- All generation and transmission located on a single node per state plus union territories (36 nodes total)
- No enforced intrastate transmission constraints

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)

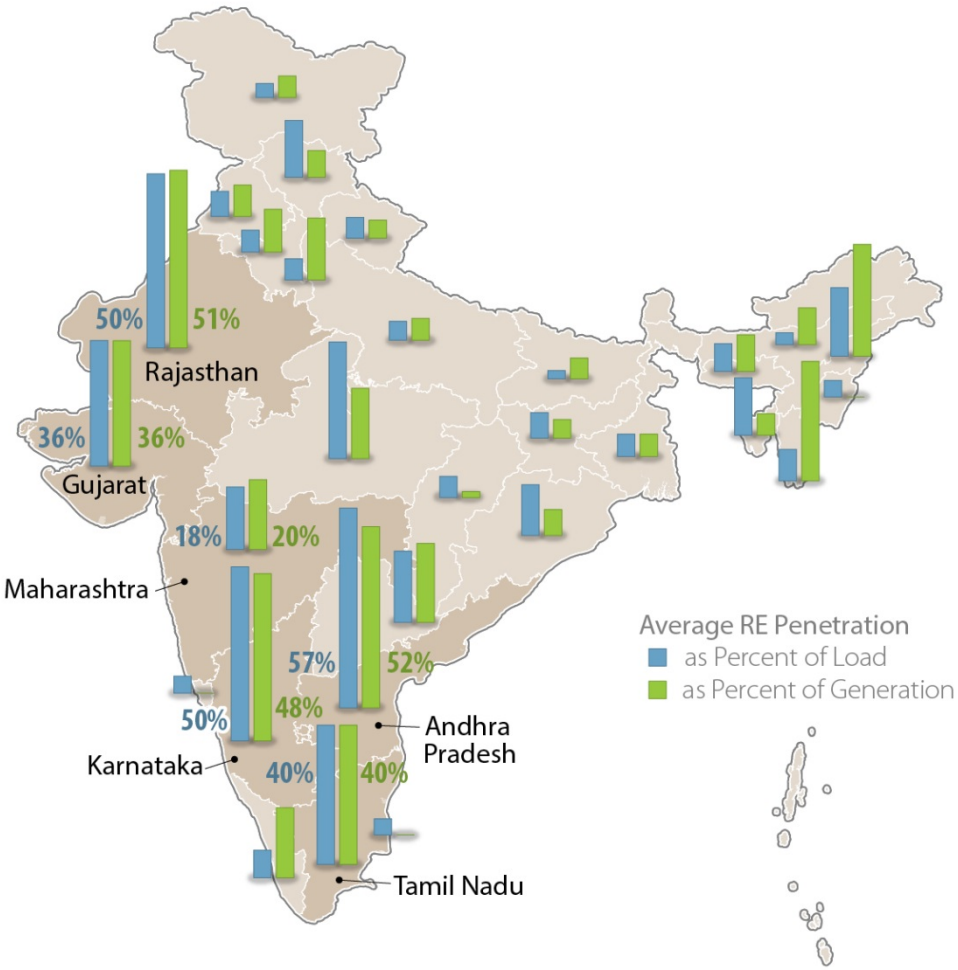
India's Power System in 2022—Achieving System Balance Every 15 Minutes

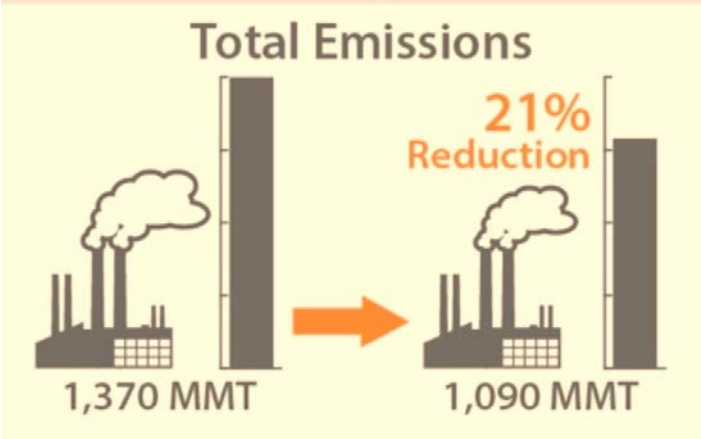


https://maps.nrel.gov/IndiaGTG/

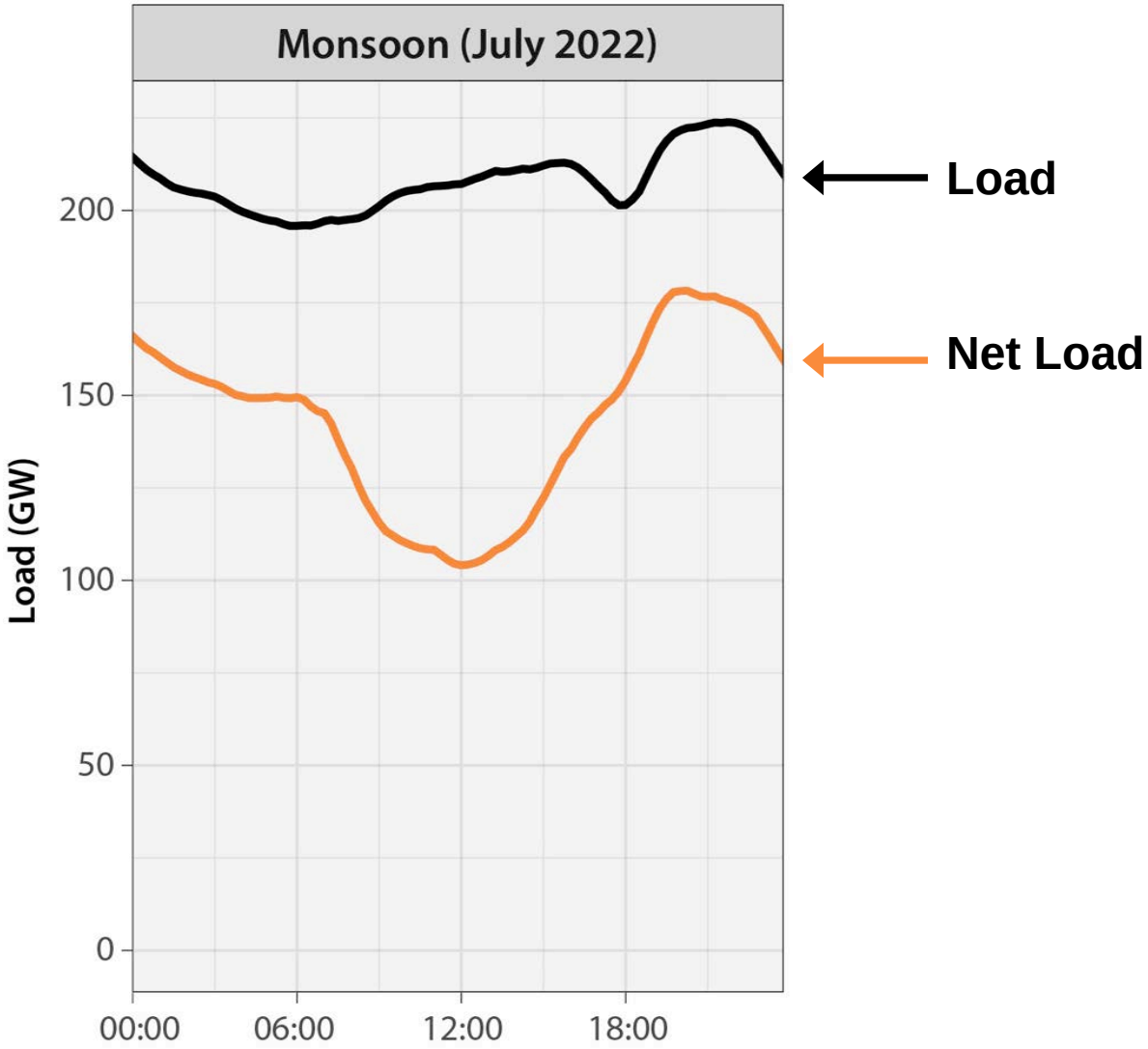
Key Findings

Annual impacts: 175 GW RE can meet 22% of India's annual electricity demand with minimal RE curtailment

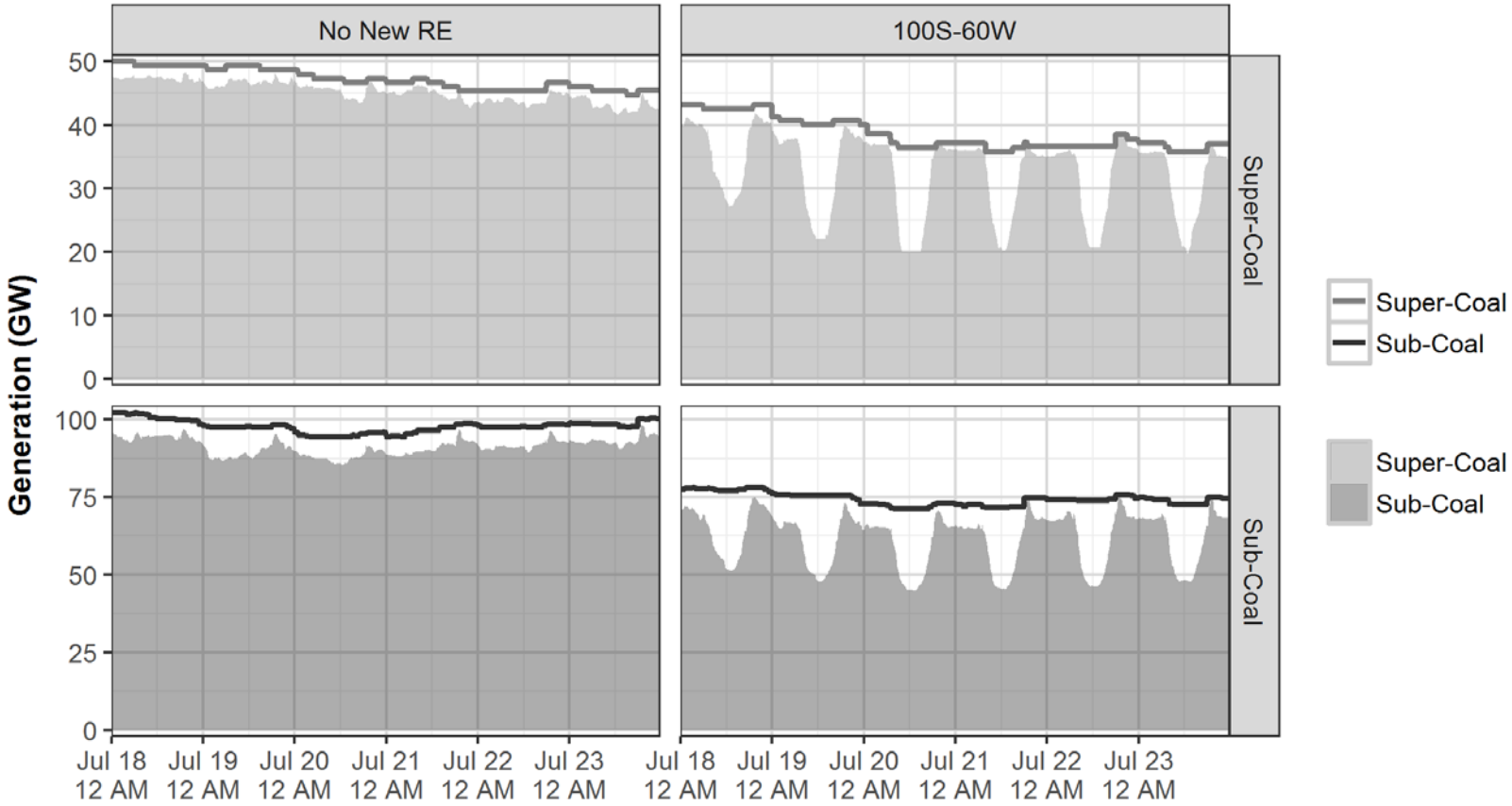




Daily impacts: Existing flexibility in the coal-dominated system can manage RE variability

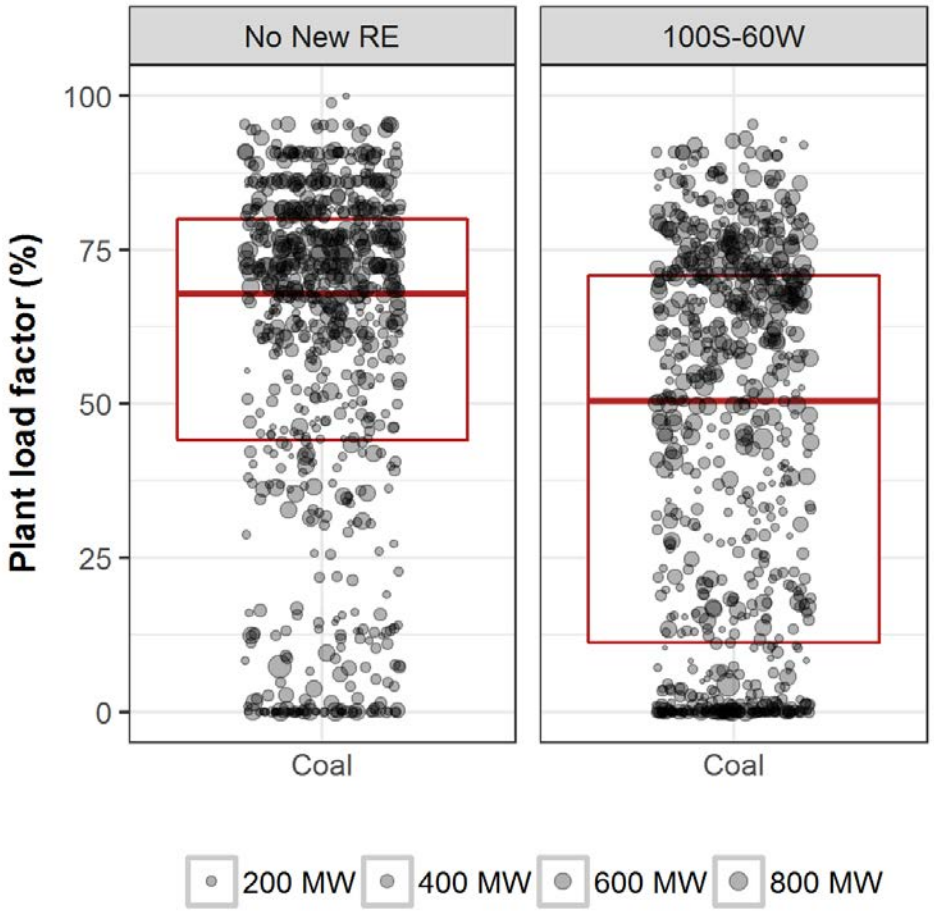


Coal units are typically backed down midday



Coal commitment and dispatch for one week in July

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



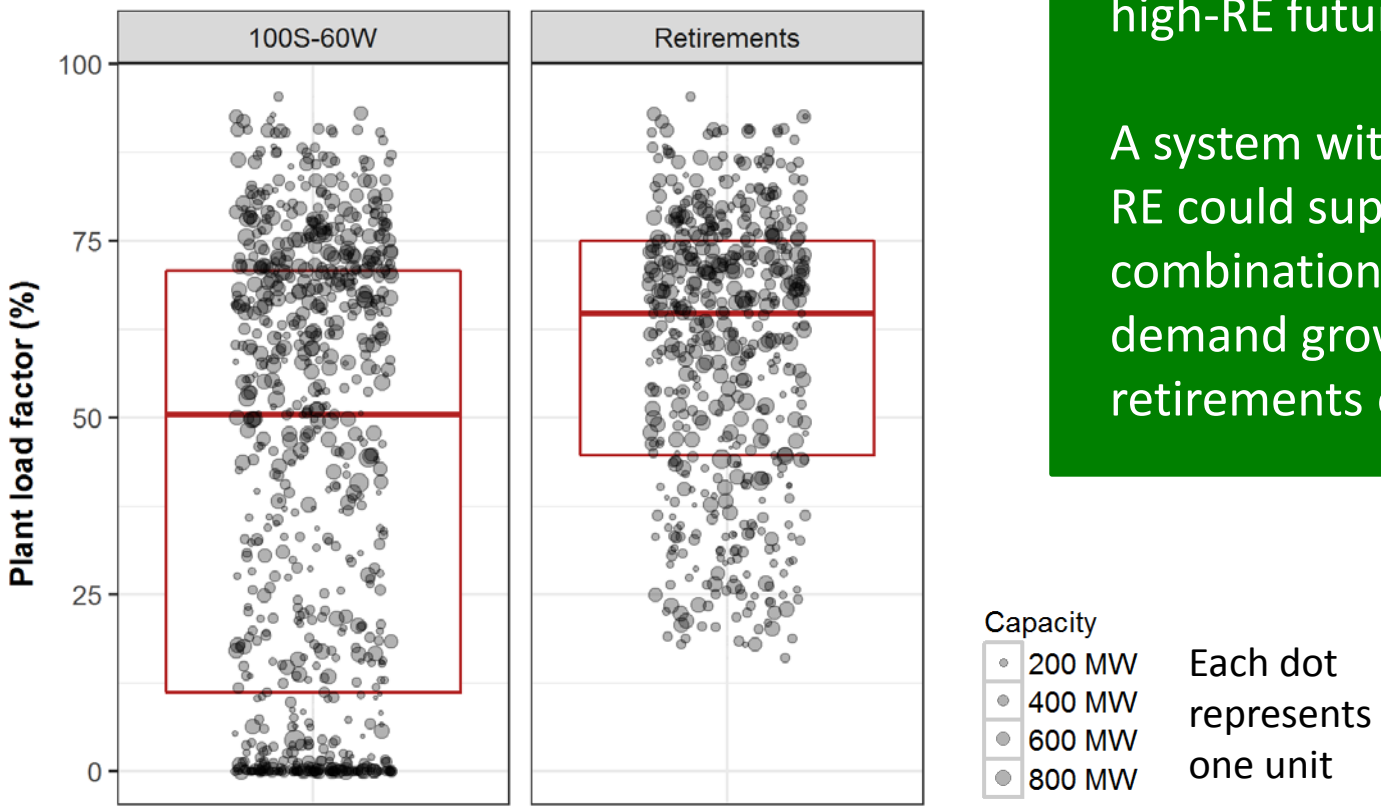
Coal capacity below 25%, and above 75% PLF

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

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

Lower technical minimums for coal plants

Cost savings	RE curtailment
State Scheduling and dispatch	**70%** Technical minimum
INR 6300 crore annually	3.5% → 1.4%
Regional Scheduling and dispatch	**55%** Technical minimum

As operated in 2014

Batteries do not add value to RE integration <u>from scheduling/dispatch perspective</u>

- 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 provide value for other reasons outside scope of study:

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

BATTERY STORAGE

100 GW SOLAR, 60 GW WIND

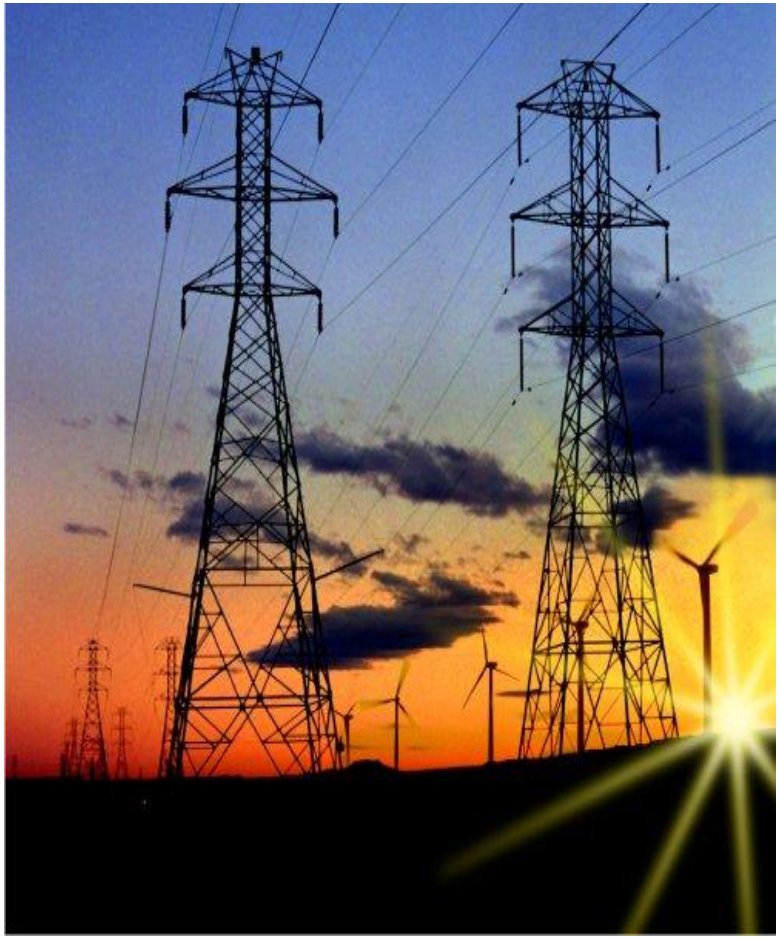
NORMAL OPERATIONS (NO BATTERY STORAGE)	2.5 GW BATTERY STORAGE
230,000 INR Crore Annual Production Cost	**0.33%** Savings annually
1.4% Renewable Energy Curtailment	**1.1%** Renewable Energy Curtailment

Low and high hydro years do not handicap RE integration

100 GW SOLAR, 60 GW WIND		
Normal operations	**Increased hydro output (+ 9.8% hydro generation)**	**Decreased hydro output (- 10.7% hydro generation)**
Production cost (230,000 crore)	- 1.9%	+ 2.3%
Coal generation (1000 TWh)	- 1.7%	+ 1.7%
CO_2 emissions (1,100 MMT)	- 1.6%	+ 1.7%
RE curtailment (1.4%)	1.4% RE curtailment	1.4% RE curtailment

Priority Takeaways

1. India's power system has significant latent physical flexibility to integrate 175 GW RE with existing plans
2. Harnessing this flexibility is the key challenge. Need appropriate regulations, markets, incentives...
3. For example, consider ways at the state level to compensate coal plants for operating flexibly
4. Additional planning could identify optimal locations for new RE and associated inter- and intrastate transmission



Source: NREL PIX 19498