GREENING THE GRID:
Advances in Production Cost Modeling for India Renewable Energy Grid Integration Study

Greening the Grid: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid uses advanced weather and power system modeling to explore the operational impacts of meeting India's 2022 renewable energy (RE) targets and identify actions that may be favorable for grid integration. The first-of-its-kind study relies primarily on a production cost model that simulates optimal scheduling and dispatch of available power generation in 2022 to resolve key questions about how India's electricity grid can manage the variability and uncertainty associated with integrating 175 gigawatts of RE, including 100 GW of solar and 60 GW of wind, to meet India's 2022 installed capacity goal.

The multi-institutional study team used two different modeling approaches—National and Regional—to answer a range of questions in appropriate levels of detail. Because of the computational intensity of these models, some simplifications to the more detailed Regional model allowed the team to explore a wider variety of scenarios.

National Model

The **National model** runs relatively quickly, which enabled the team to explore more questions and spot major trends in power system operations from a national perspective, such as major energy flows across the country and roles for coal-dominant states with less RE potential to facilitate system balancing. Validated by system operators, the National model shows:

- Day-ahead scheduling based on site-specific RE generation forecasts
- Economic dispatch that matches the 15-minute operational timescale used by grid operators in India
- Transmission flows between (but not within) states
- Operations based on unique operational characteristics for each generator (variable costs, heat rates, outages)
- Plant-specific hydro generation based on historic operations
- Technical and commercial value of changes to operational practices (e.g., increased market trades, increased flexibility of coal plants).

To investigate system operations in each of the states with the potential for significant growth in RE capacity, the study team also used a higher-resolution model that includes intrastate transmission details. This **Regional model** builds upon the same inputs in the National model but includes all transmission lines and substations within each of the states in the Southern and Western regions plus Rajasthan. Therefore, the Regional model provides more robust views of localized operations and can offer more relevant insights to support state-level planning. Together, the models provide reasonable insight for:

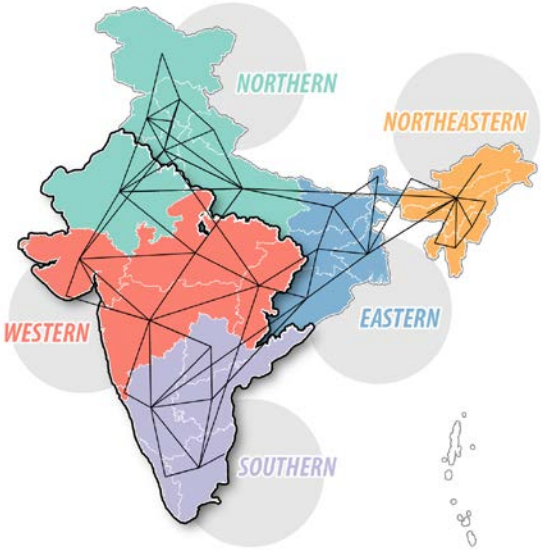
- Assessing impact of in-state transmission constraints on system flexibility
- Analyzing impact of RE site selection and state-level transmission planning on RE curtailment
- Describing how various RE integration strategies would likely impact operations of conventional and RE generation at the state level.

Coupling a lower-resolution National model with a higher-resolution Regional model offers the advantage of computational efficiency. The shorter run time of the National model allows for a larger number of scenarios and strategies to be analyzed than would be the case if a more computationally intensive high-resolution model were used. In addition, policy at the central level can benefit from analysis of higher-level issues without undertaking the additional resource-intensive analysis needed to support state-level planning. With the insights obtained from the National model, more meaningful scenarios can be selected for rigorous analysis using the higher-resolution Regional model.

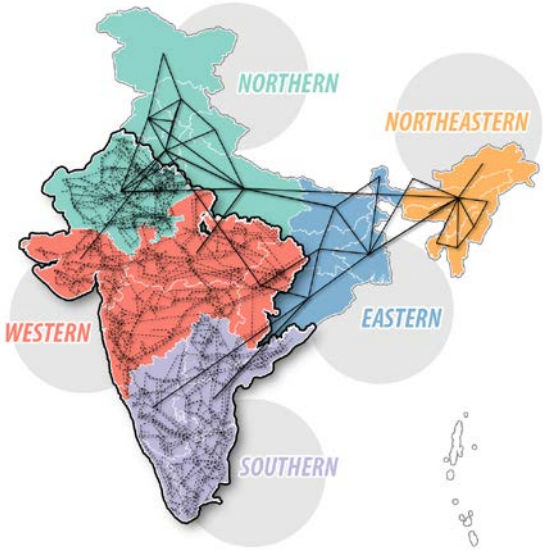
MODELS AT A GLANCE

Common Modeling Assumptions for the Regional and National Models

- 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
- DC power flow
- Central Electricity Authority and central transmission utility 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
- Peer-reviewed by 100+ member Grid Integration Review Committee (4 meetings in each of 3 locations)



Transmission representation in the National Study



Transmission representation in the Regional Study

National Model

- Highlights trends and big-picture outcomes
- Captures value of RE integration strategies based on state-level optimized RE site selection and transmission development
- All generation and transmission located on a single node per state plus union territories (36 nodes total)
- No enforced intrastate transmission constraints

Regional Model

- Informs detailed state-level planning
- Captures complex relationships among scheduling and operations, transmission, RE site selection, and generator flexibility with regard to RE integration
- 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 kilovolts)

This work is conducted under a broader program, Greening the Grid, which is an initiative co-led by India's Ministry of Power and the U.S. Agency for International Development, and includes collaboration with the World Bank Energy Sector Management Assistance Program and the 21st Century Power Partnership. The modeling team comprised a core group from the Power System Operation Corporation, Ltd. (POSOCO), which is the national grid operator (with representation from the National, Southern, and Western Regional Load Dispatch Centers), National Renewable Energy Laboratory, and Lawrence Berkeley National Laboratory, and a broader modeling team drawn from Central Electricity Authority, POWERGRID (the central transmission utility), and State Load Dispatch Centers in Maharashtra, Gujarat, Rajasthan, Tamil Nadu, Karnataka, and Andhra Pradesh.

Learn more: www.nrel.gov/india-grid-integration/

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