Integrating VRE in India's power system

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12 April 2021

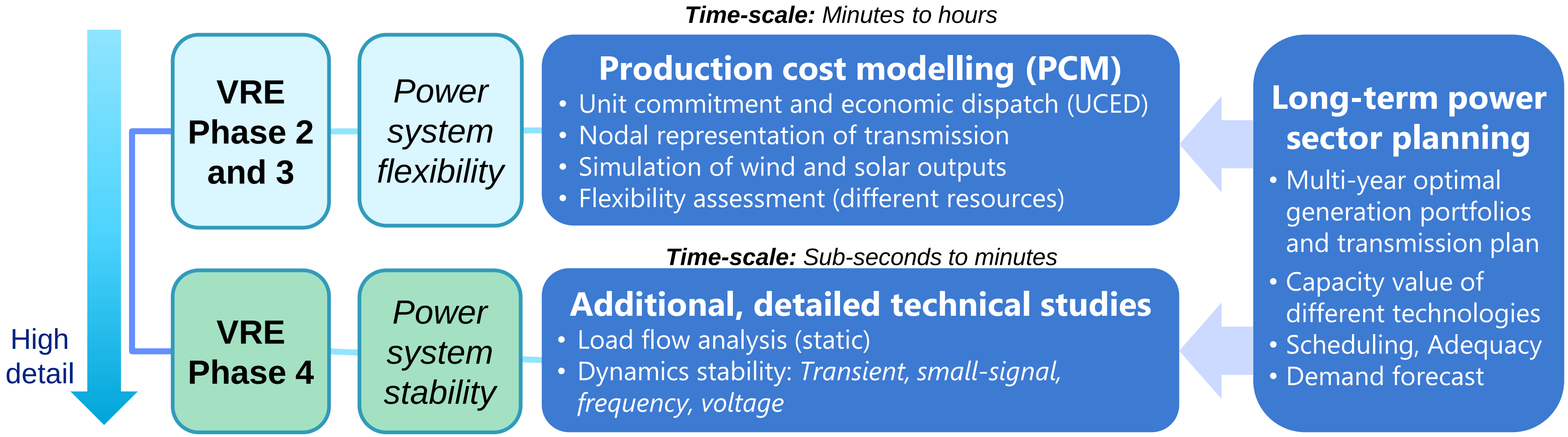
International Energy Agency

IEA clean energy transitions program (CETP) work in India

- As part of the Clean Energy Transitions Programme, the IEA has been collaborating with India on system integration of RE in cooperation with Niti Aayog since 2018
  - national workshop in Delhi with NITI Aayog and the Asian Development Bank
  - four regional workshops in Delhi, Chennai, Pune, and Kolkata.
- A key outcome from the regional workshops was the recognition that power system flexibility challenges, solutions and priorities in India are very different for each state depending on the local context
- Based on this finding, with sponsorship from the British High Commission and in partnership with NITI Aayog, the IEA organised a series of state-level Power System Transformation Workshops since 2019 with the objective to help inform each state government's actions with a policy roadmap.
  - Three state-level power system transformation workshops to date: Maharashtra (February 2020), Gujarat (October 2020) and Karnataka (January 2021)
  - Workshop reports for each state can be found online and an integrated national report connecting the findings from the state level work will be released later this year.
- To support the work the IEA has developed two detailed power sector production-cost models to illustrate flexibility challenges and solutions – a five-region model of India and a Gujarat state model.

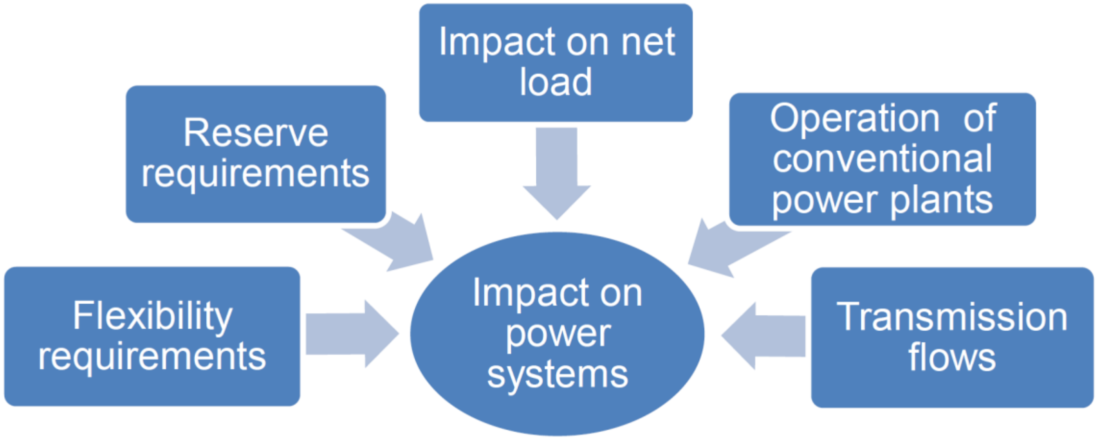
Links: https://www.iea.org/events/power-system-transformation-workshop-1-state-of-maharashtra
https://www.iea.org/events/power-system-transformation-workshop-2-state-of-gujarat
https://www.iea.org/events/power-system-transformation-workshop-3-state-of-karnataka

Integrated power system modelling studies with VRE



- Traditionally, power sector modelling tools/studies are not integrated: cap expansion; PCM; technical
- With increasing VRE, there is a need to prioritise and integrate different existing modelling studies
  - Focus on PCM in future scenarios to assess system flexibility and the role different resources
  - Linking the modelling tools to the timescale and VRE phases (and penetration)
- These are the current modelling efforts at the IEA - a number of grid integration case studies
  - Linking and integrating different models (WEM, ETP and PCM) and sector coupling

Purpose of the technical modelling studies

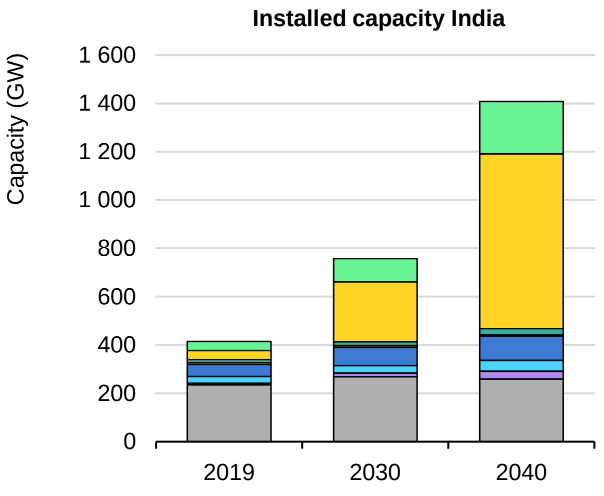


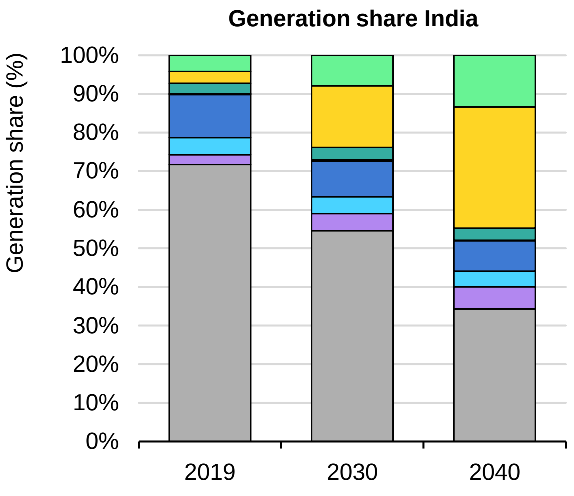
- Analyse technical capability and options for the power system to accommodate greater shares of solar PV and wind
  - Considers both technical and economic aspects
- Production cost modelling with 1-hour time resolution in 2030 with 2019 as validation year
  - Assess the impact of VRE on the system and value of flexibility resources including: flexible power plants; pumped storage hydropower, battery energy storage systems; demand response; transmission reinforcement

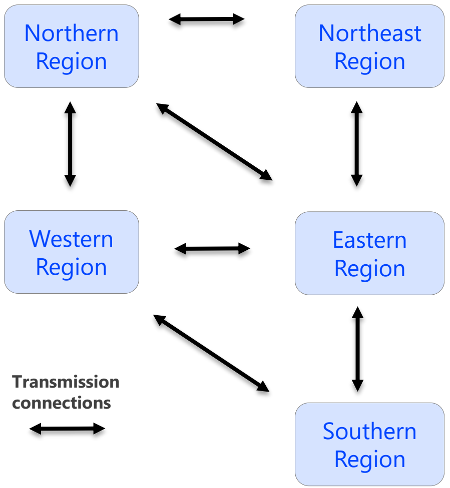
India RE integration and flexibility modelling

India regional model overview

- Supports other modelling at the IEA by going into more technical detail including transmission and power plant operational characteristics
- 5 regions based on the existing control arrangements in India where 5 areas are managed by regional load dispatch centres (RLDCs)
- Base year (2019) and 2030 stated policies scenario (STEPS) based on IEA World Energy Outlook



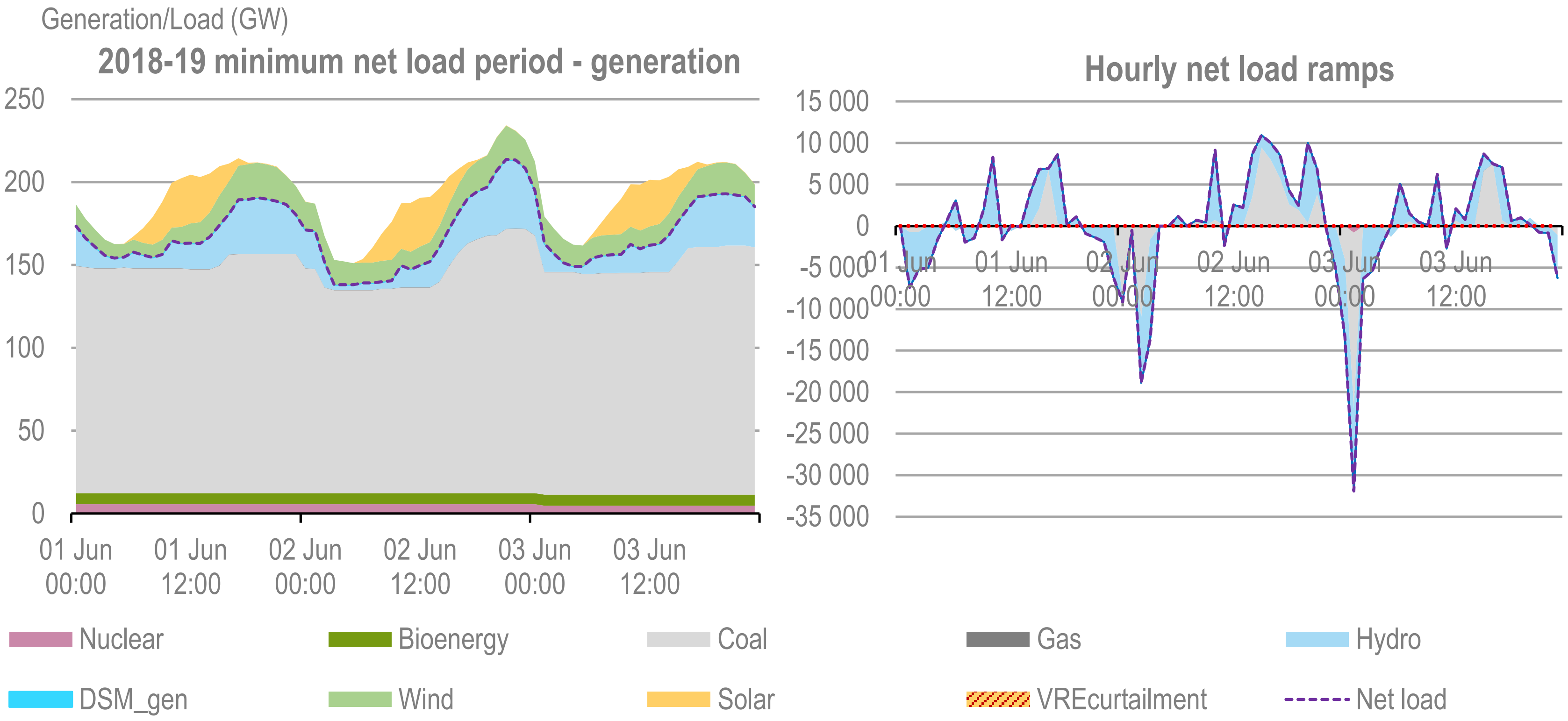




Coal, Nuclear, Gas, Hydro, Oil, Other renewables, Solar PV, Wind

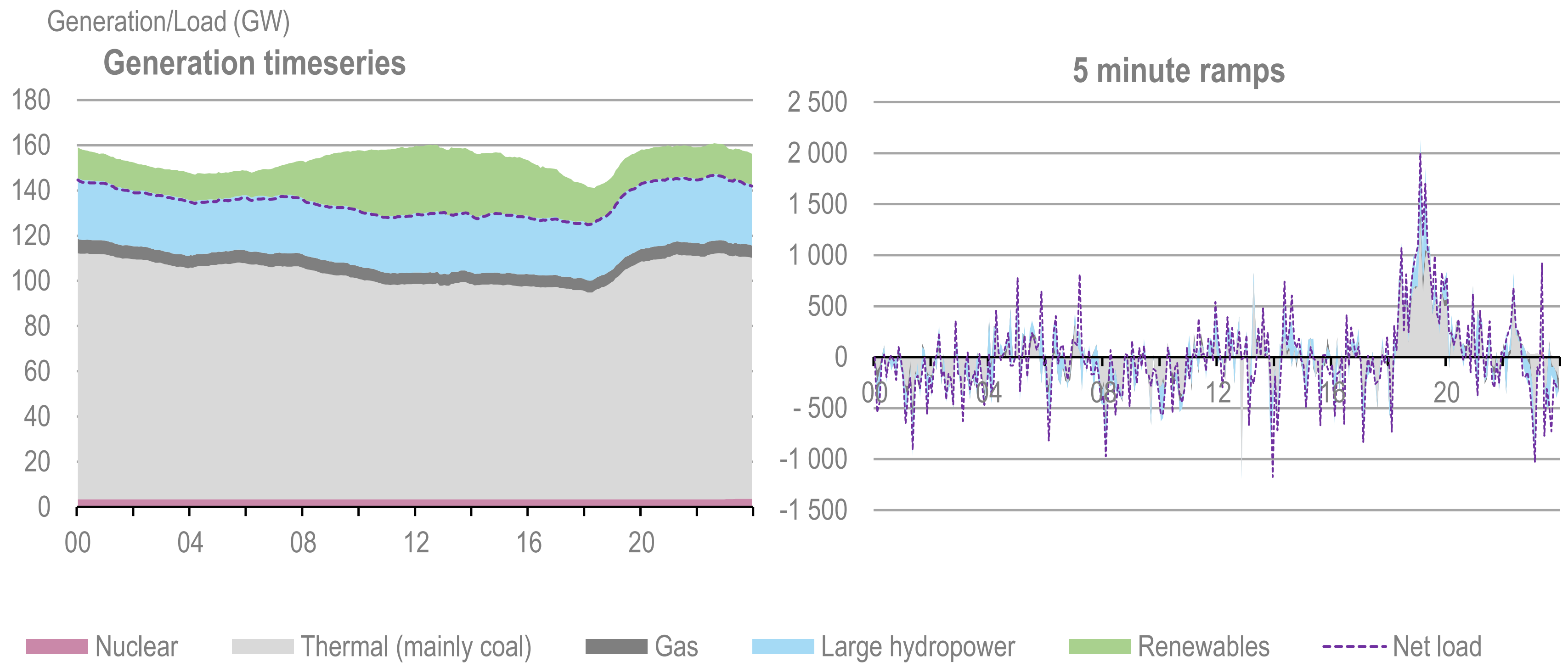
India is a coal-dominant system today, with strong ambitions to increase the share of solar and wind energy.

India 2019 base IEA regional model



Power system flexibility in India today is predominantly provided by coal power plants as well as hydropower.

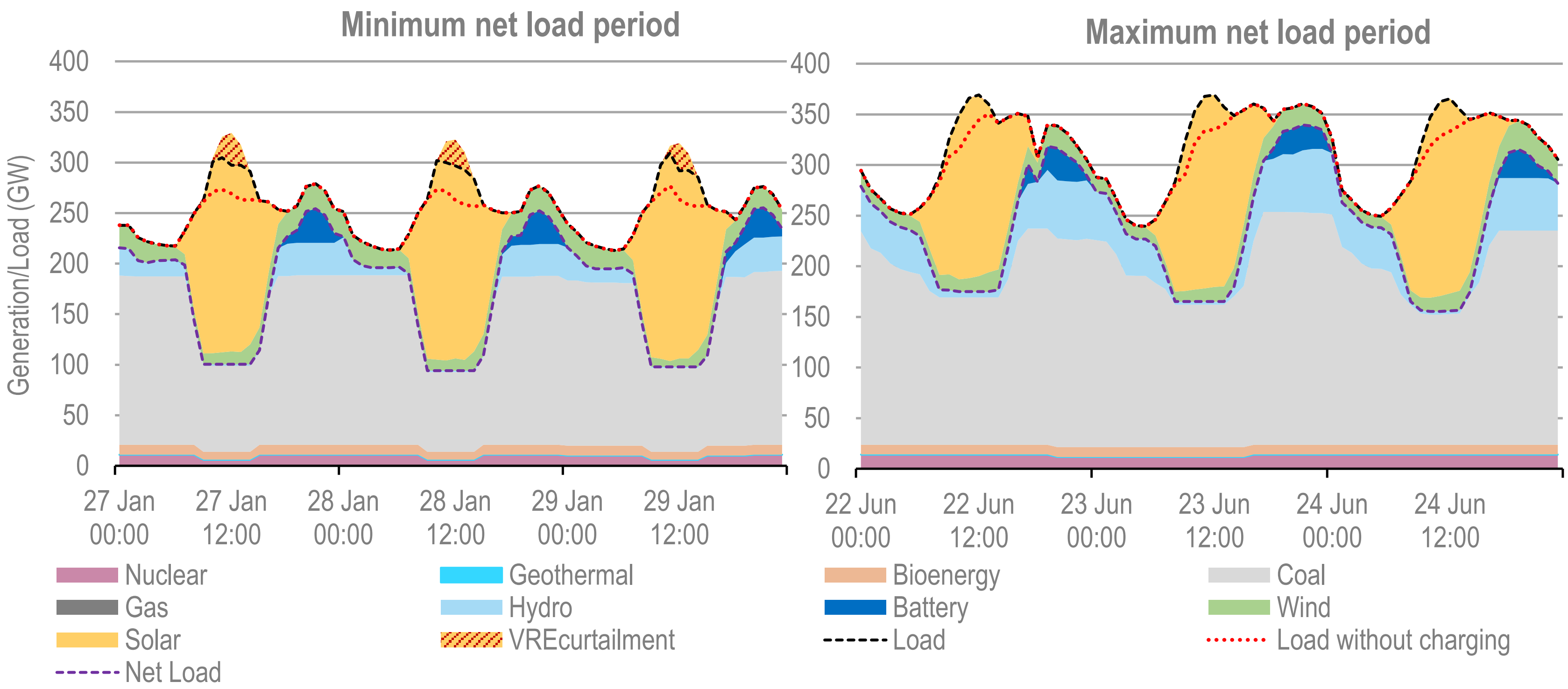
India 2020 live 5 minute data (selected states)



Real time historical data also illustrates that shorter term (5-minute) ramps today are provided predominantly by coal. In this example day ramping requirements reach 400MW/minute during the evening peak.

Data source: http://meritindia.in/

India 2030 STEPS model

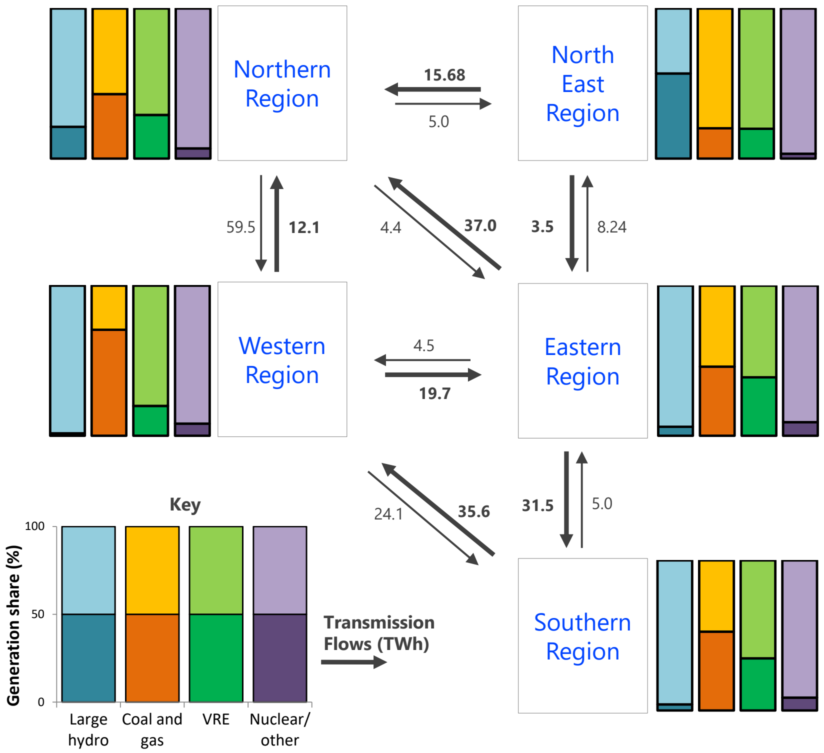


In 2030 diverse flexibility options will enable India to integrate much higher shares of variable renewable energy: increased power plant flexibility, transmission, demand response and energy storage.

Trade between regions becomes increasingly important

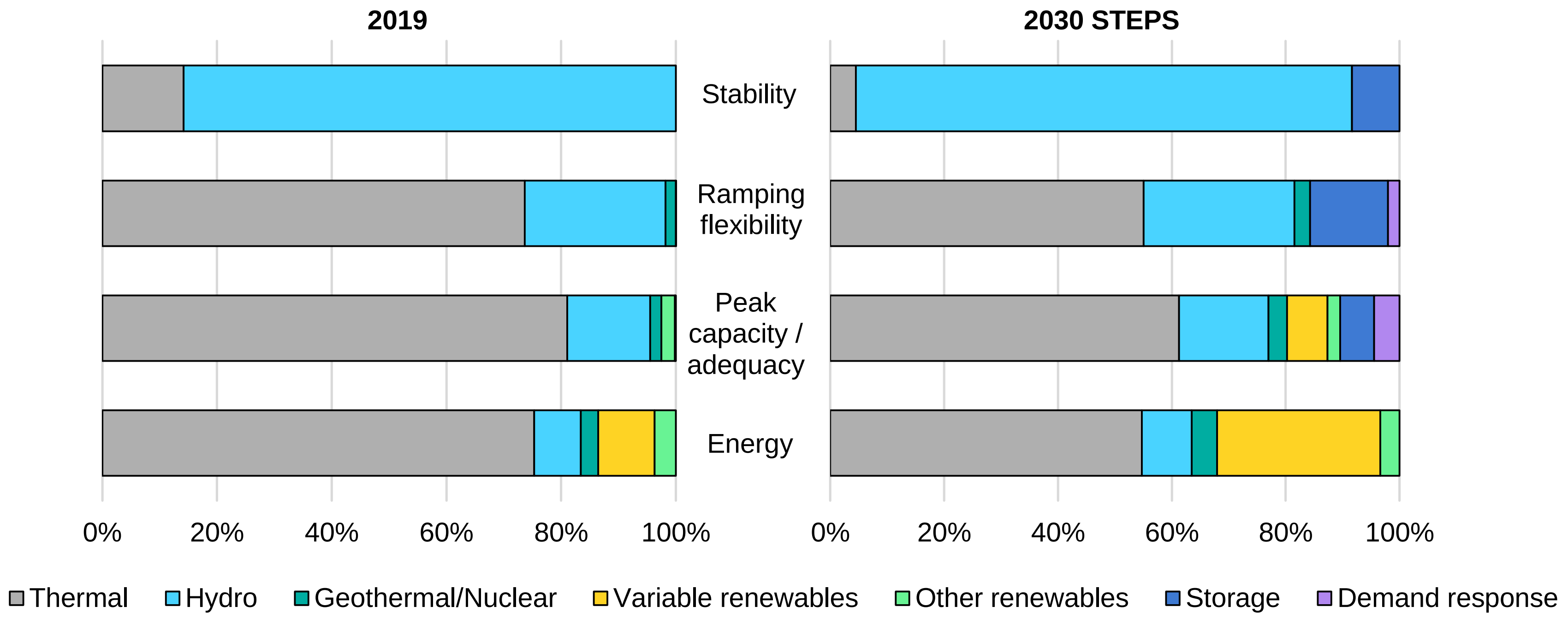
- Interregional trade is crucially important in India today but is also limited by existing dispatch practices as well as system security considerations affecting utilization of transmission corridors

- By 2030 in the STEPS interregional flows increase by around 40%, and constraints could drive as much as 2.5% renewables curtailment if today's limitations are not overcome



Trade between regions becomes increasingly important, allowing resources to be shared between regions.

Electricity security services in India will be provided by more diverse technologies

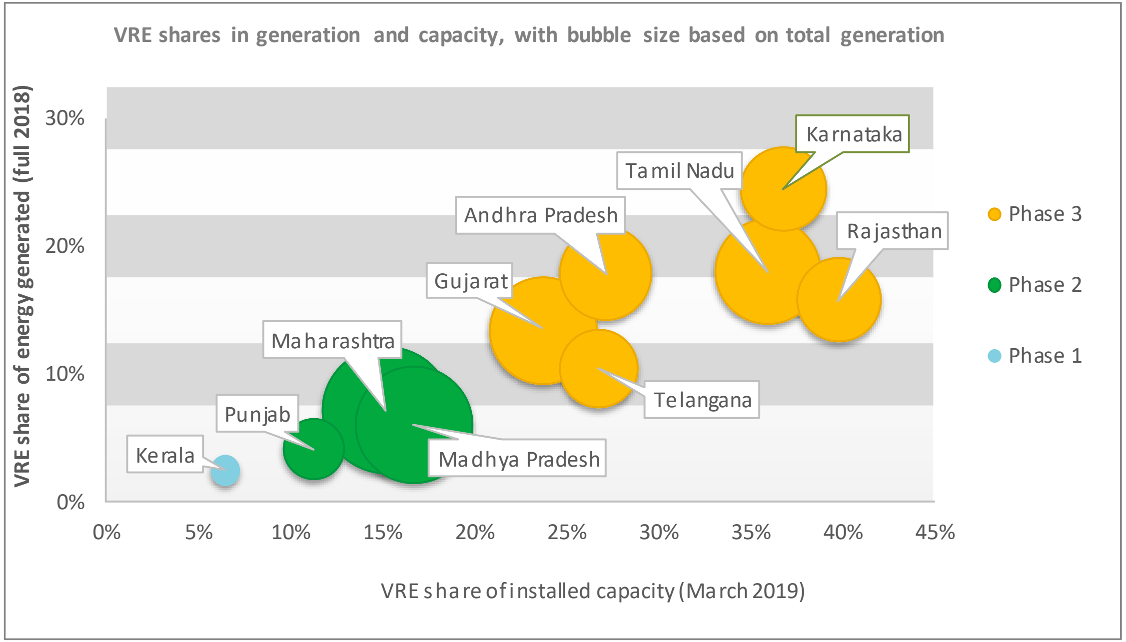


The services required to maintain electricity security are provided by a more diverse mix of technologies as variable renewables increases, while the role of thermal plants and particularly coal remains central.

State-level flexibility modelling - Gujarat

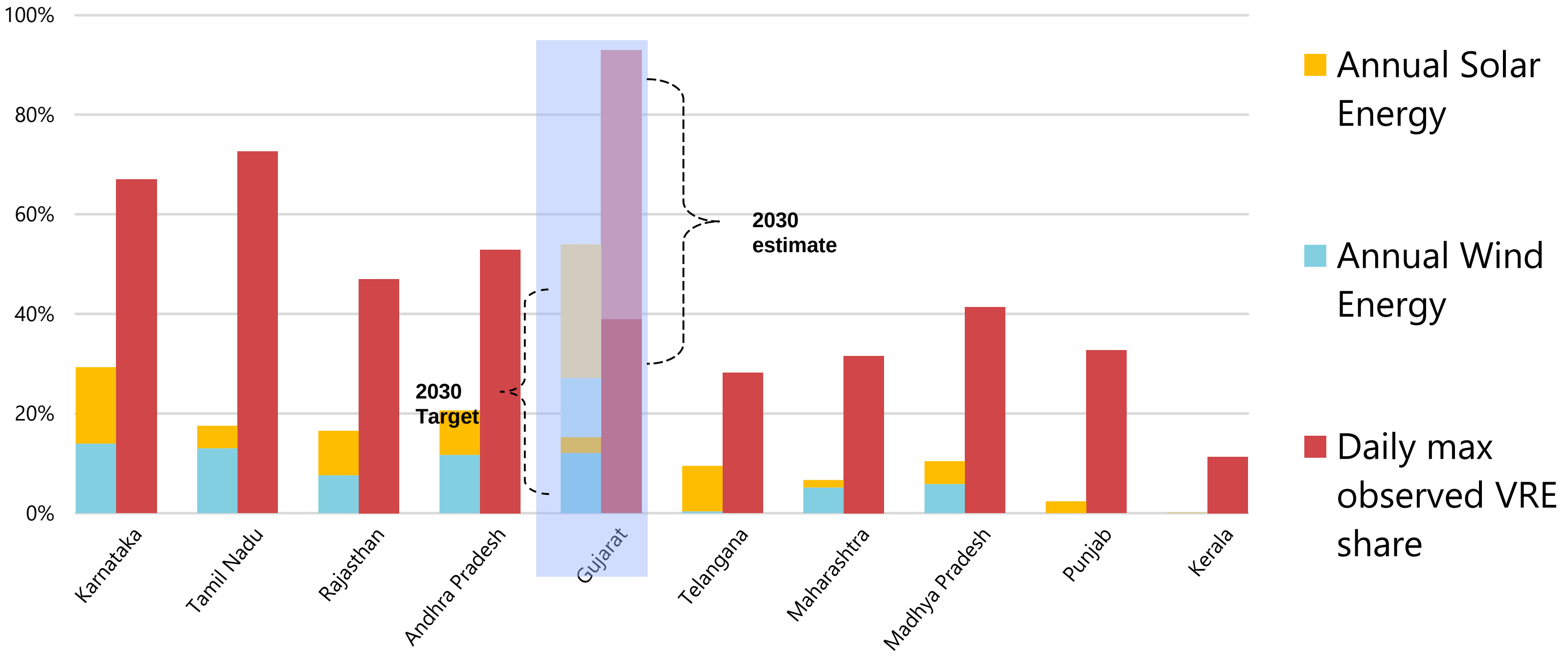
IEA clean energy transitions program (CETP) state level analysis

- Some renewables-rich states in India have much higher amounts of solar and wind than the national average
- 6 states are already in Phase 3 of SIR, where solar and wind determine the operation of the system
- IEA works with Niti Aayog and local partners on System Integration of RE with focus on State level analysis in 2019-2021
- Renewables integration status is highly state specific
- IEA detailed modelling analysis focuses on the state of Gujarat, in collaboration with CER IIT Kanpur



India VRE rich states comparison – Gujarat in Phase 4 in 2030

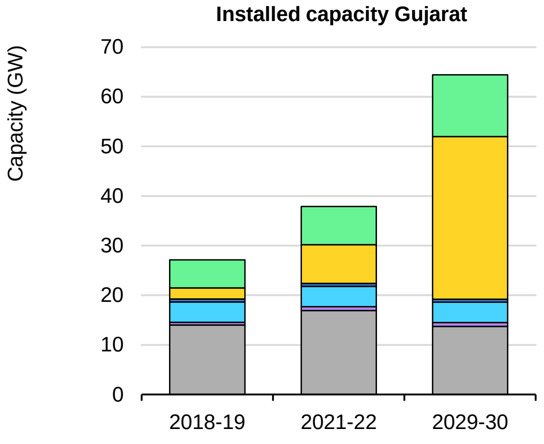
Electricity generation from VRE as a percentage of all generation in VRE-rich Indian states, 2019/20

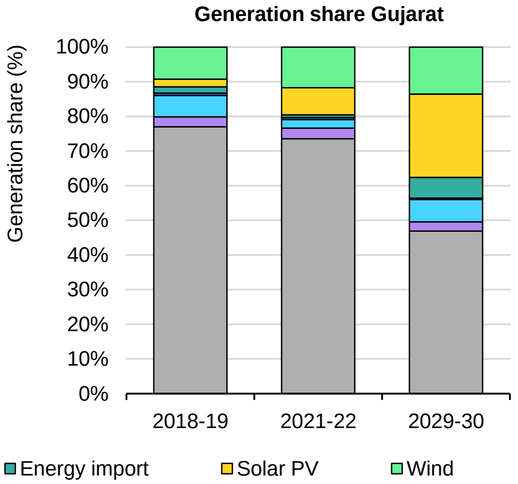


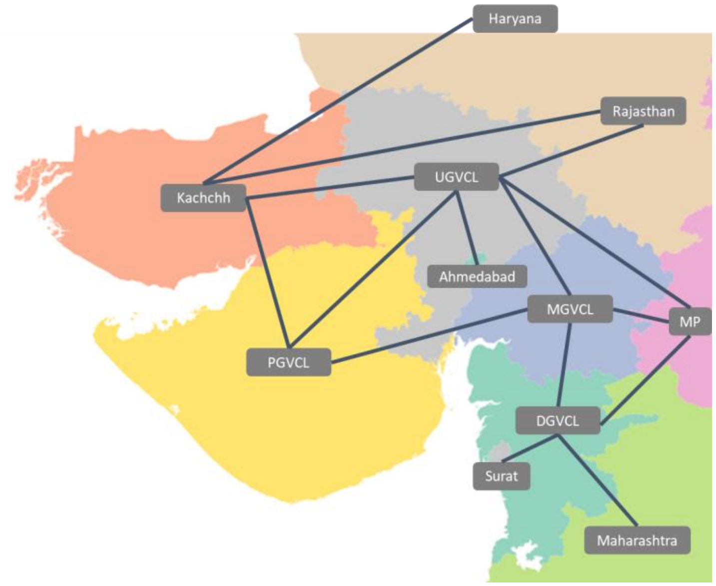
Achieving the 2030 VRE targets of Gujarat results in a significant increase of the daily peak VRE share, placing the state in phase 4.

Structure of the Gujarat state model

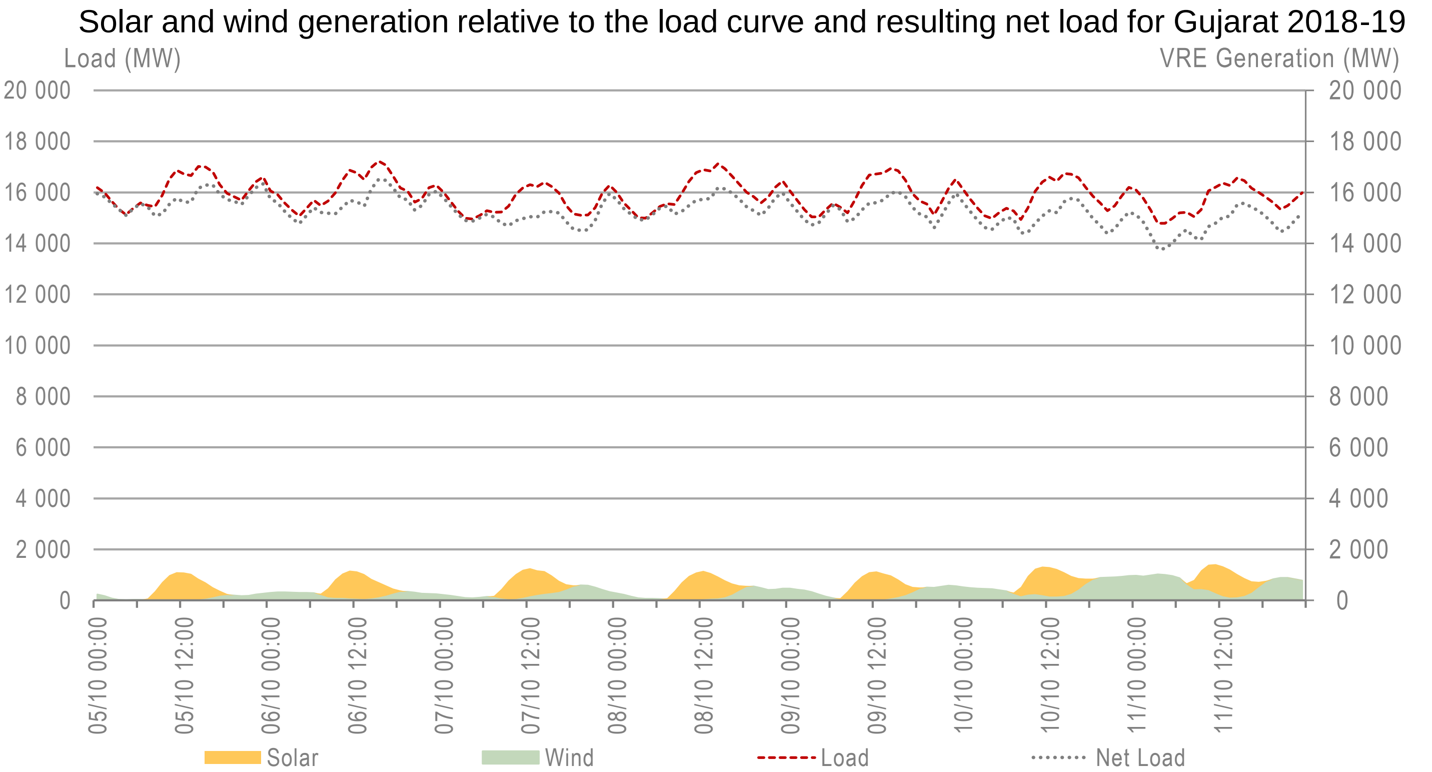
- Intrastate nodes - one each for PGVCL, Kachchh, UGVCL, MGVCL, DGVCL, Surat and Ahmedabad
- Inter-state nodes - Rajasthan, MP, Haryana, Maharashtra
- Demand is modeled on the intrastate nodes, along with the generation capacity in that region
- Inter-state nodes only have generation capacity contracted by Gujarat and are the source of short term electricity market purchases (and sales)
- Commercial software tool (PLEXOS)





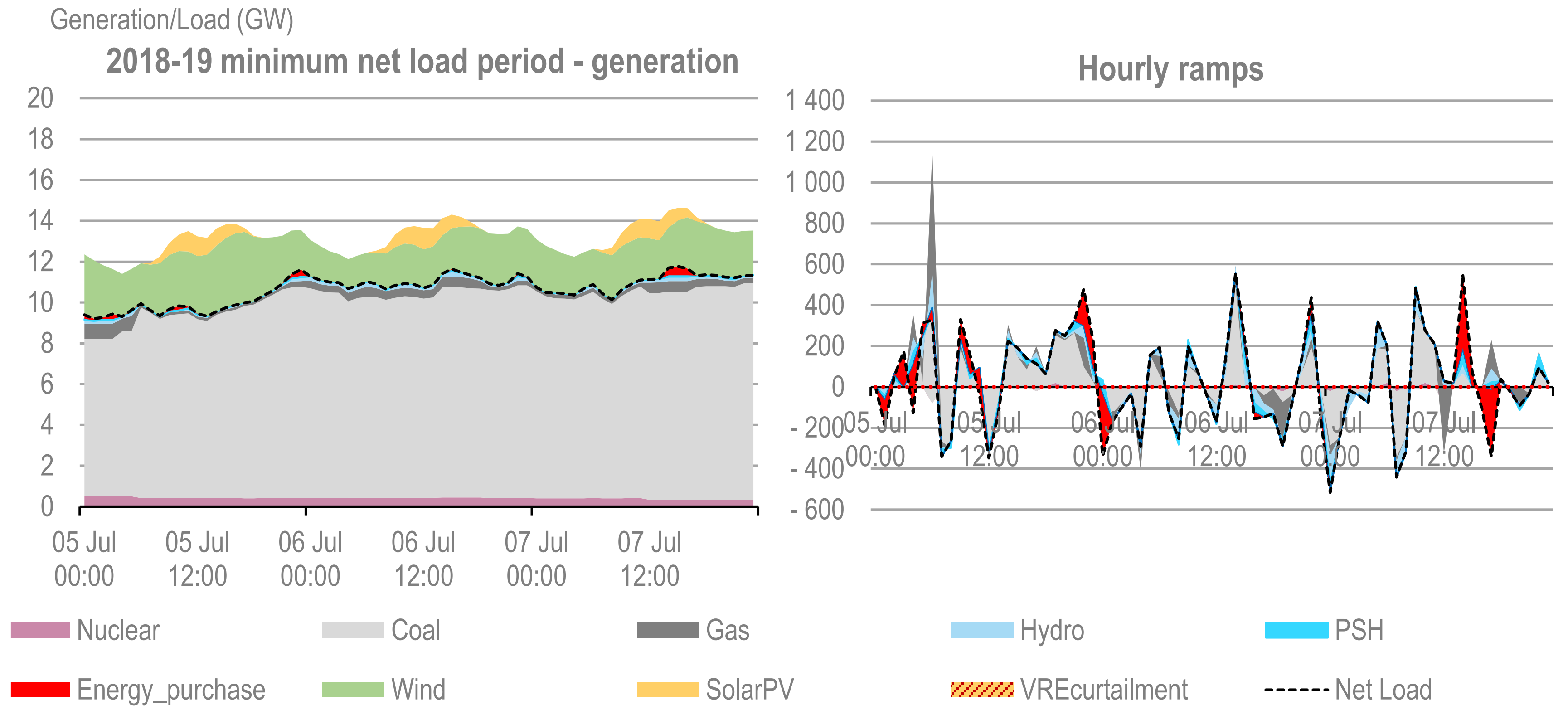


Complementarity between solar and wind generation and demand



Solar and wind in Gujarat today are complementary with higher wind output at night when solar generation is zero. Solar generation in particular helps to meet afternoon peak demand.

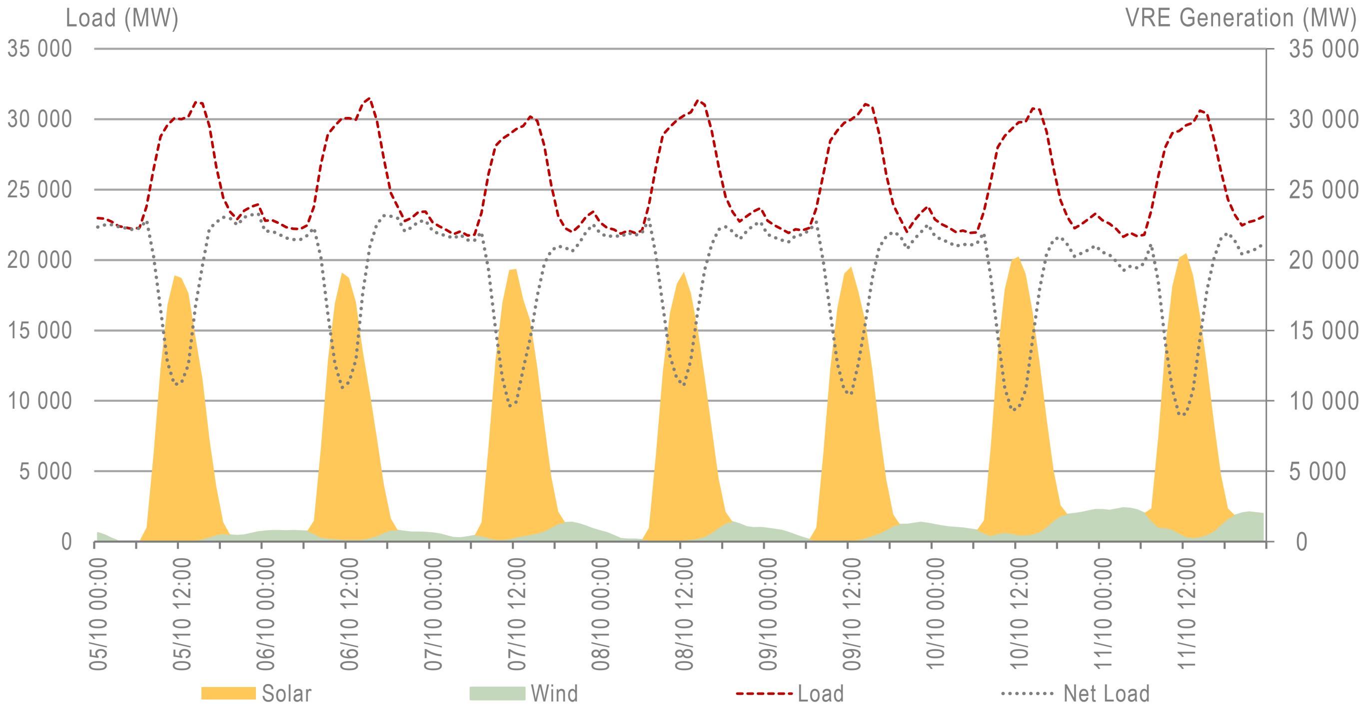
Year 2018-19 Gujarat base model



Gujarat successfully integrated 12% solar + wind generation without curtailment in 2018-19. The main source of system flexibility currently comes from coal-fired power plants.

Increasing solar in 2030 results in integration challenges

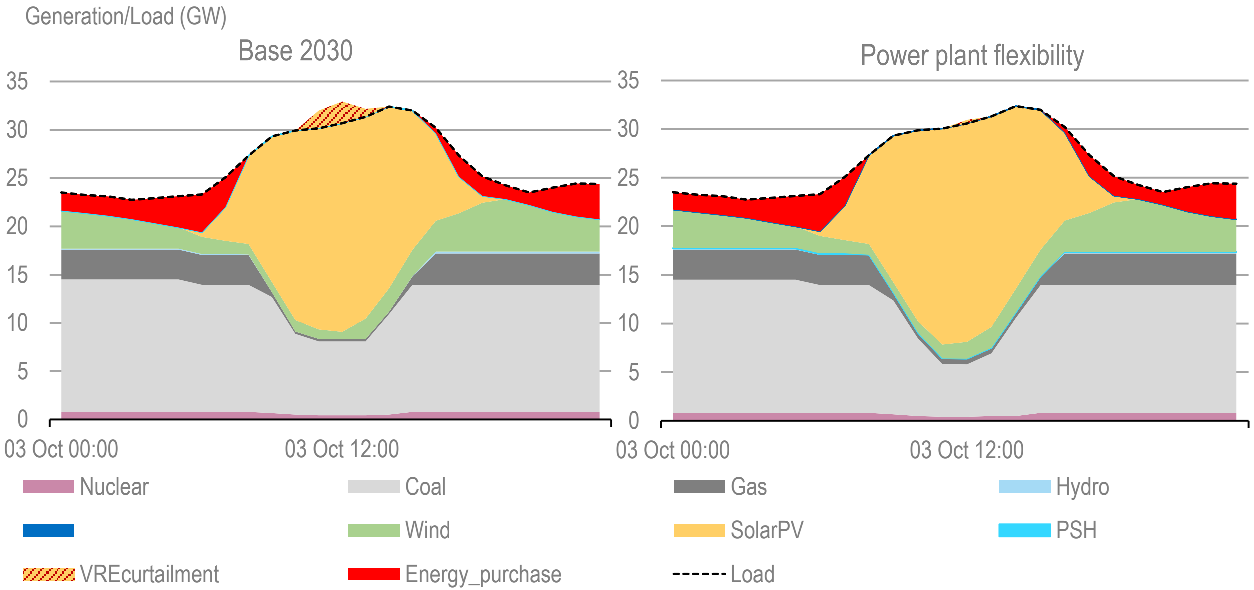
Solar and wind generation relative to the load curve and resulting net load for Gujarat 2029-30



Solar and wind in Gujarat today are complementary with higher wind output at night when solar generation is zero. Solar generation in particular helps to meet afternoon peak demand.

Increased power plant flexibility helps accommodate high VRE periods

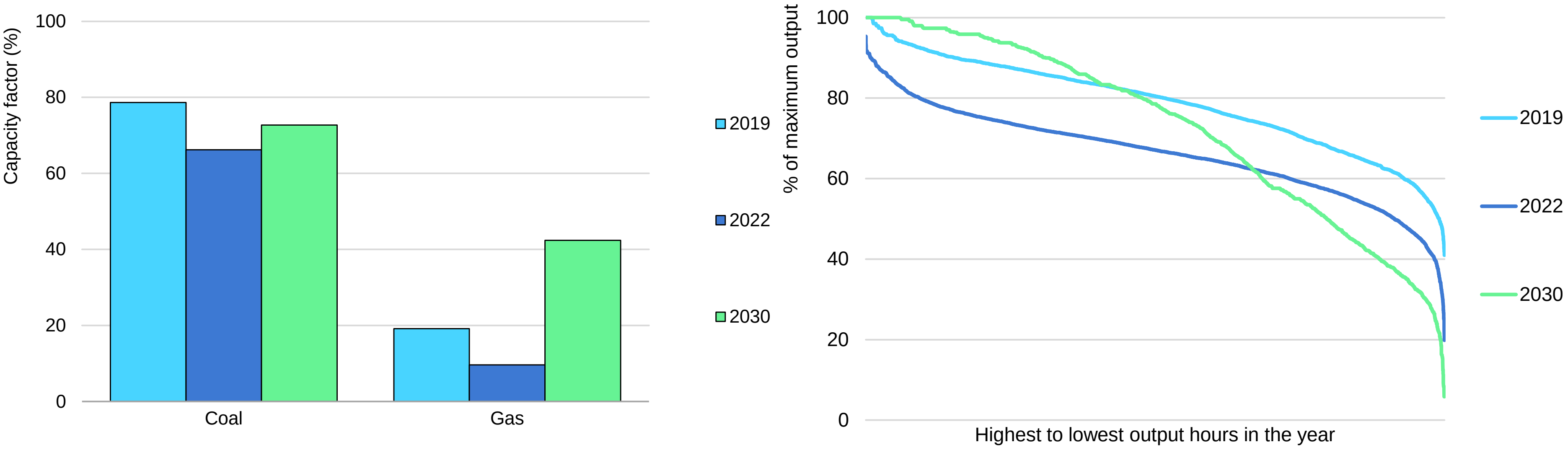
Daily dispatch curve with and without increased power plant flexibility



Increased power plant flexibility in 2030 reduces curtailment (6.3 to 5.5%) by allowing power plants to better accommodate solar generation and variable costs (2.2% reduction) mainly due to reduced startups.

To 2030, the operating pattern of coal needs to shift

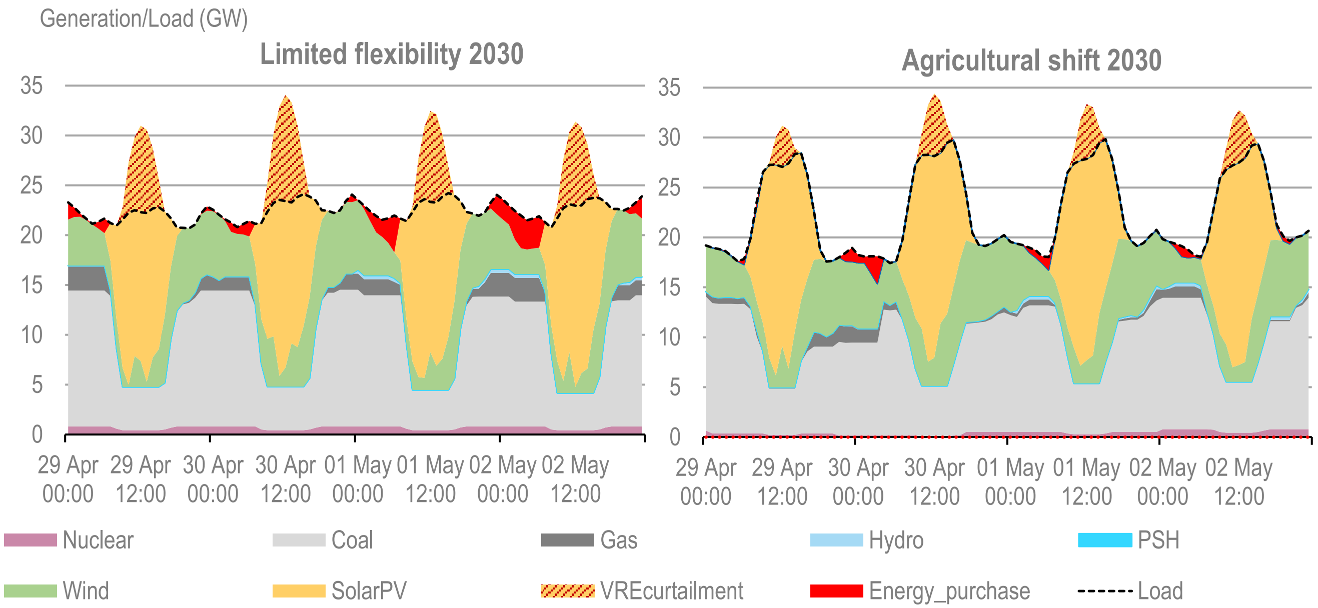
Capacity factors for coal and gas (left) and fleet utilization by hours in the year for coal (right).



Changes in plant utilization in FY2021-22 due to new build, weak demand growth (decline in coal / gas capacity factor). Out to 2029-30, plant load factors increase a little from 2022 despite increased VRE due to reduced capacity and load growth, however this masks a large change in operating patterns as conventional plants are less focused on energy and more on flexibility

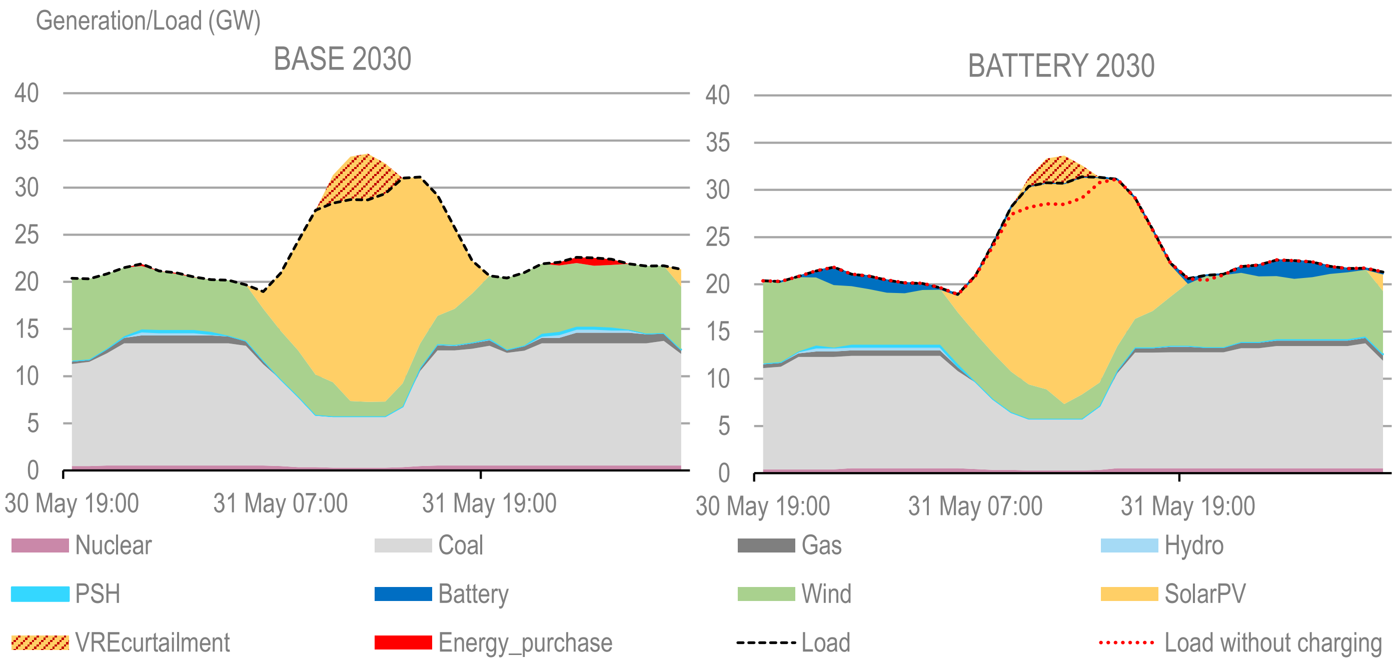
Demand response is a key flexibility option in 2030

- Existing plans for shifting agricultural pumping loads (19% of state demand) to the daytime help demand to coincide with solar output
- Eliminates curtailment (3.3 to 0%), and unit starts (with 40% reduction for coal and gas) and reduces variable costs from fuel, startups and ramp costs (9.4% overall reduction)
- Reducing high demand periods helps meet capacity needs (21GW to 19GW max net load) and reduces market purchases (32% reduction)
- Impacts on water usage should also be considered, as Gujarat agricultural regions are also at high risk of water stress



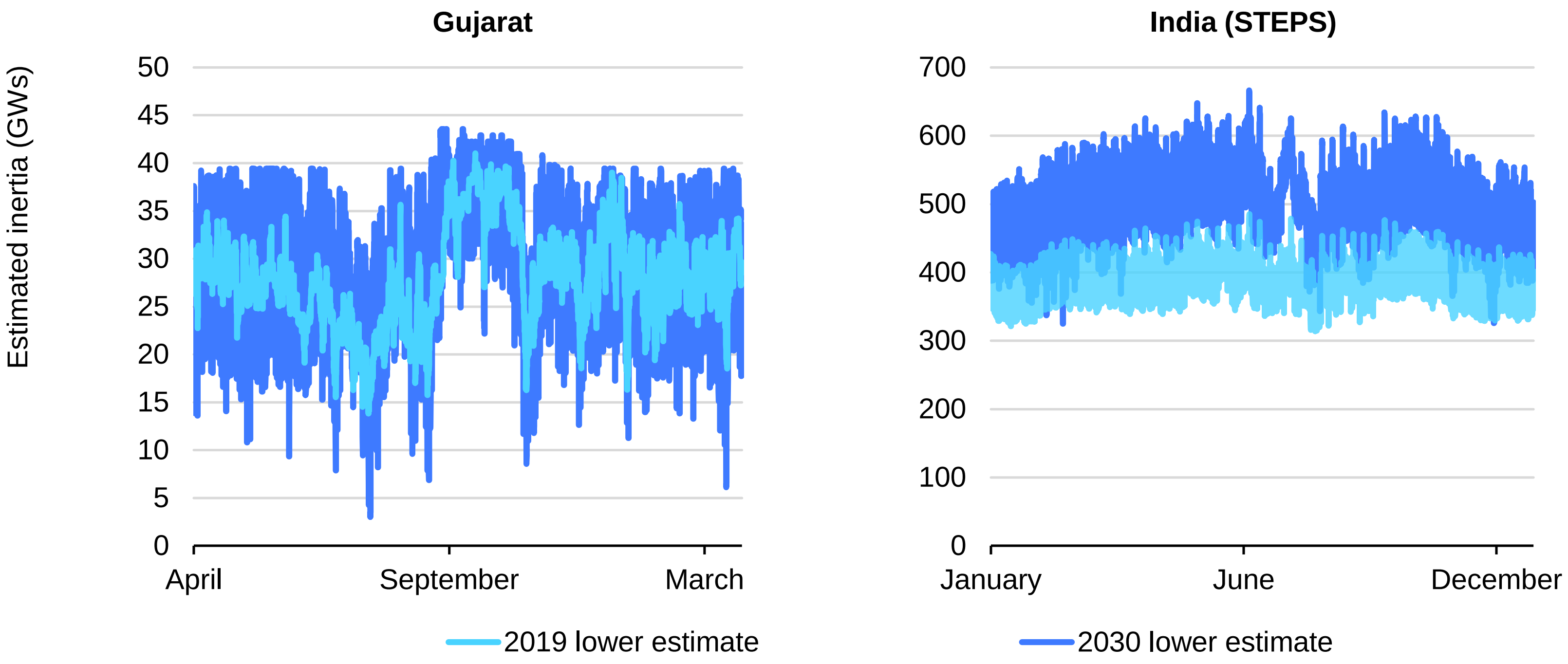
Source: agricultural demand and shifted profiles from work of Khanna, 2020

Battery storage absorbs VRE generation and helps meet peak demand



Battery storage allows high solar output during the day to be stored for later use to meet evening demand. This results in a reduction in variable costs including 1.8% reduction in variable costs (startup, fuel and ramp costs) as well as over 30% reduction in market purchases

Impacts on inertia



While the inertia provided at a local level will decline in high renewables states, at the whole India level minimum inertia is not expected to decline in the STEPS in the coming decade and inertia is not expected to present a challenge to stability.

Summary of findings

- India today is already successfully integrating around 10% solar and wind generation and current ambitions will see this reach close to 30% in the coming decade
- Local renewables penetrations in renewables rich states are much higher, resulting in state-specific integration challenges today which are expected to intensify in the coming decade
- The dominant source of power system flexibility today comes from coal-fired power plants, with an important role for interconnection between regions as well as agricultural demand response in states such as Gujarat.
- Coal-fired power plants will continue to play a central role in India in the coming decade for energy, adequacy and short-term flexibility needs.
- As India moves to much higher shares of variable renewables, flexibility from a more diverse range of sources becomes increasingly important: power plant flexibility, strong inter-regional trade, demand response and energy storage.
- System stability is not expected to be an issue in the coming decade, despite declining provision of inertia in renewables rich regions

Commercial and contractual considerations

Spot markets and physical PPA’s

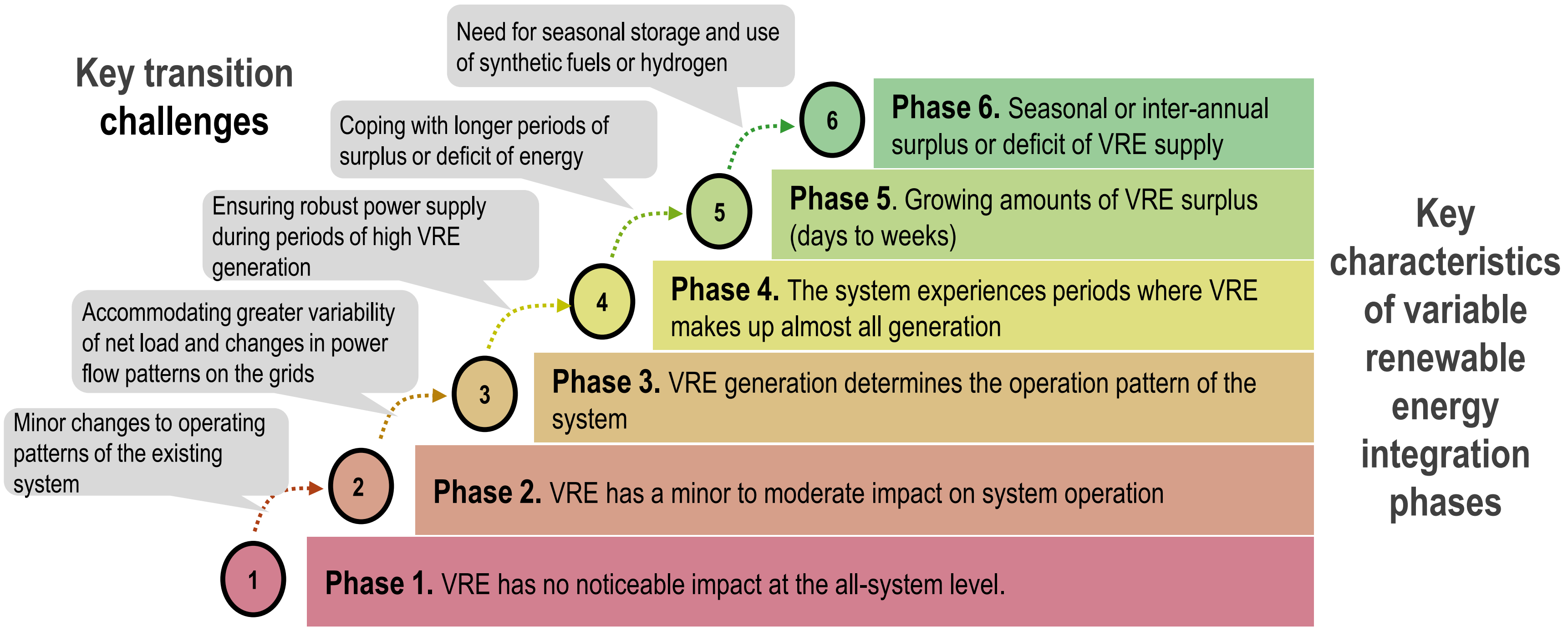
- India has introduced **day-ahead and real time markets**
- Real time markets were introduced to compliment day-head especially helping VRE
- Attracting liquidity ha been a challenge
- **Only 10 percent** of generation is traded in short term markets
- 90 % is traded on long term contracts between DISCOMs and generators
- This is creating a **lock in effect** for DISCOMs, who are already struggling with finances
- The dispatch and flexibility is **negatively** impacted by the physical PPA’s

Solutions to increase flexibility

- Discussions are ongoing about switching from **physical to financial** PPA's
- Changing existing PPA's vs implementing it with new PPA's
- Financial PPA's require a good **reference price →** efforts to increase trading in day-ahead markets are needed
- Requirements on DISCOMS to improve financial situation, generation cost is part of that but not the only problem (revenue collection)
- Tradition of **litigation** makes changing existing contractual structures very difficult
- New generation may be required to use spot markets

The IEA's participation in this event was made possible through the Clean Energy Transitions in Emerging Economies programme has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952363.

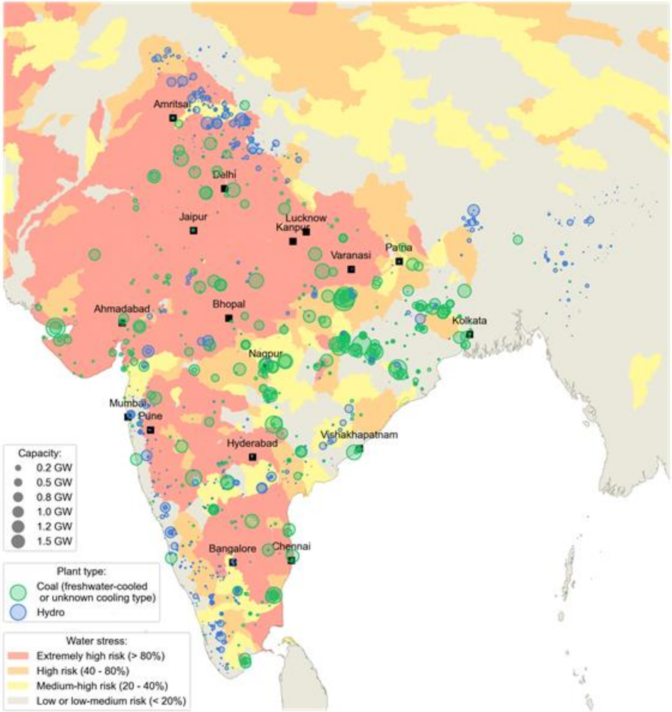
Six phases of system integration help make international comparison



Key challenges in each phase that should be addressed for moving up to higher phases of variable renewable energy (wind and solar) integration

Agricultural areas in India overlap with high water stress

- Irrigation methods used in India have high evaporation rates
- By 2030, CEEW estimates that the agricultural sector will be responsible for about 87% of all water withdrawal in India (a CEEW estimate) if current irrigation practices such as flood-irrigation continue to be used.
- In India, 20% to 47% of irrigation water losses could be saved by 2030 to 2050 using different irrigation methods. The current low water efficiency can further decline with demand shifting because water evaporation is significantly higher in the middle of the day compared to the mornings, late afternoon or evenings.
- Further targeted analysis is required to estimate the specific impacts of demand shifting on water evaporation and water efficiency.



Water stress needs to be taken into account when considering agricultural demand flexibility