Flexibility of coal plants

7. Develop state-level assessments to determine if coal power plant flexibility is a preferred (most cost-effective and least polluting) solution in the specific state. Develop state criteria to select the coal power plants best positioned for flexibility investment. Develop state regulatory mechanisms to encourage new investment in selected coal power plants and redesign compensation for flexible coal power plants. Further, coal power plant investment needs to be weighed against investment in flexibility sources from other parts of the system (storage, demand response and grids).

8. In the longer term, state agencies will need to play an important role in assessing and setting flexibility requirements at the state level on a plant-by-plant basis to balance state-level demand and supply. State-level ancillary services regulations and markets, combined with improved spot market participation, would help remunerate flexible plant operation on a competitive basis with other flexible resources such as demand-side response, storage and grid flexibility.

Interstate trade and wholesale market reforms

9. Strengthening the power trade across states could reduce the curtailment of renewables and provide access to low-cost generation in other states. This requires neighbouring states to improve the co-ordination of their scheduling and dispatch. There is also a need to weigh the costs and benefits of potential new transmission investments against the costs and benefits of other flexibility options for cost-optimal end results. States where solar and wind generation levels are expected to go beyond 100% of demand (in numerous hours a year by 2030) are recommended to build strong interstate interconnections.

10. Support regional and interstate transmission studies (such as that of the CSTEP). Such studies should then be assessed alongside those that address alternative power system flexibility resources, such as demand-side response, storage and power plant flexibility options.

11. Conduct national-level assessment of the costs and benefits of investments to promote synchronous connections with Bangladesh and Nepal, in addition to those already existing for Bhutan, to enlarge the geographical footprint for balancing.

12. State and central governments need to review and possibly reform the current state regulation and national market rules to give new participants equal access to compensation for providing flexibility. Identification of barriers to competition for

new technologies (such as batteries) can be the first step for the state regulators. The development of new ancillary services and an ancillary services market would provide an opportunity to consider all new technologies from the start. Additionally, state grid codes can be reviewed and updated to ensure system-friendly connection and flexibility requirements are in place for new solar and wind projects, including distributed solar (rooftop and pumps).

13. The current practice of relying on physical PPAs for resource adequacy may not be the most cost-effective tool for achieving resource adequacy. Thus, the states could consider creating alternative resource adequacy mechanisms and encouraging the use of financial PPAs. In the longer term, a sophisticated financial market for power sector products could be introduced in India.

Recognising environmental concerns with flexibility

14. If the objective is emission reductions, the government should be aware that flexibility options in themselves can both decrease emissions and increase them, for example by enabling lower-cost coal generation to contribute more to the mix. Incentives for emission reductions and for preferential dispatch of lower-emission technologies may be needed in some systems to avoid unintended consequences.

15. Co-ordination across the states’ water, energy and power departments may need further emphasis going forward. State governments should support the improvement of water management practices and also support targeted analysis that estimates the impact of agricultural demand-shifting and pumped-storage hydro retrofits on water evaporation and water efficiency. The improvement of water management practices should also result in a more flexible, secure and resilient power sector by ensuring water availability for agricultural demand response, pumped-storage hydro and conventional power plants in periods of high water stress, such as during heatwaves, flooding or droughts.

System strength and inertia

16. With the future increase in solar and wind, the renewables-rich states will experience periods when wind and solar represent the majority of generation, which may affect system stability. It will be important that states monitor local system strength and inertia requirements.

Annex: Power system modelling and methodology

India Regional Power System Model and Gujarat State Power System Model

To provide a deeper analysis of the impact of increasing renewables and the role of flexibility in India, the IEA has developed two power system models: the India Regional Model and the Gujarat State Model. Both models undertake a techno-economic analysis using a production cost modelling approach, with a focus on the operational aspects for a one-year "snapshot" of 2030, in addition to 2019 as the reference year. Both models are hourly, and enrich the IEA's power sector modelling by including interregional transmission as well as detailed operating characteristics such as operating costs, plant technical minimum operating levels, minimum up and down times, start-up times and ramp rates. It is important to note that an hourly time resolution does not fully capture aspects such as plant-level ramp rate restrictions, and that metrics such as renewables curtailment may be underestimated relative to a more detailed time resolution.

For both models, emissions have been calculated according to estimated fuel characteristics and plant efficiencies. Although the two models are not directly linked, the emissions from power imports in the Gujarat State Model are estimated using hourly emissions intensity from the India Regional Model, and hourly import volumes.

IEA India Regional Model

To allow for a more detailed analysis of flexibility needs, this model includes a representation of the five regions controlled by the regional load dispatch centres and the interregional transmission connections, which are based on CEA plans and account for transfer capability limitations reported by POSOCO. Production profiles for renewables were represented, along with operating costs and characteristics for thermal technologies. Hourly simulations were based on unit commitment and economic dispatch.

For the India Regional Model, three 2030 scenarios were included in addition to the 2019 base year:

- The *STEPS case* includes a full range of flexibility solutions (trade between regions, demand-side response, batteries and power plant flexibility).
- The *transmission downside case* includes transmission transfer capability limitations in 2030.
- The *combined low flexibility case*, in addition to transfer capability limitations, excludes flexibility from power plants, demand response and batteries.

Load profiles for the India Regional Model were based on detailed analysis from the World Energy Outlook STEPS scenario to provide hourly electricity demand curves. Annual electricity demand projections for each end use by sector relied on national macro indicators such as population dynamics and economic growth, integrating the latest policies. The potential for demand-side response by end use was developed based on the projected demand in each region. Power generation capacity expansion in India was determined on the basis of current and proposed policies and the value-adjusted levelised cost of electricity. Projected capacity for existing and new technologies was made available for dispatch. The capacity expansion is aligned with India's nationally determined contribution and the Paris Agreement.

IEA Gujarat State Model

The Gujarat State Model is based on a state-level demand forecast and historical hourly demand provided by CER, IIT Kanpur. Agricultural demand response is based on the analysis by Khanna. While further demand response measures are important to analyse, these were beyond the scope of the project, in part due to challenges of readily accessing detailed end-use data. The generation capacities were based on Gujarat government targets, taking into account the announced objective to add no new coal capacity.

The model takes a "contracted capacity" approach so that only capacity contracted by Gujarat is represented, including out-of-state capacity (i.e. central plants allocated to Gujarat). As a result, a large amount of planned renewables capacity in Gujarat that is intended to be contracted to other states (20 GW in the Kutch hybrid park) is not included in the model. It is worth noting that this capacity, depending on how it is integrated into the grid locally in Gujarat, could potentially further increase the integration challenges beyond the results presented in this report.

The Gujarat State Model is separated into four main regions based on the DISCOM areas in Gujarat, in addition to one separate node for the renewables-rich Kutch region, two nodes for the cities of Surat and Ahmedabad, and external nodes in Haryana, Rajasthan, Maharashtra and Madhya Pradesh for out-of-state plants contracted to Gujarat. Transmission between regions is based on 400 kV and above lines that already exist. No transmission expansion was included in the state model as the constraints between the DISCOMs were not found to be a driver of integration challenges or increased costs in the scenarios studied. The flexibility options included and their sizing were based on consultation with the Gujarat government and other stakeholders. While the Gujarat model is not integrated into an all-India model, energy imports are allowed in from the external nodes within the limits of the transmission constraints.

In addition to the base scenario for FY 2018/19, eight different scenarios are presented here for FY 2029/30. The reference scenario is a limited flexibility case where no additional flexibility is developed relative to today. For the flexibility cases, each individual flexibility option is added separately to the inflexible case so that they are considered in isolation. In addition, one scenario with no additional flexibility, but with a higher share of wind, is included.

IEA Gujarat State Model 2030 scenario summary

Scenario	Description
Limited flexibility	Flexibility at 2019 historical level, base scenario with which to compare the options below
Pumped storage hydro	Addition of two upgraded hydro plants with pumped operation by 2030: 242 MW + 196 MW
Coal plant flexibility	Increased coal power plant flexibility – reduced minimum stable levels and increased ramp rates
Agricultural shift	Additional agricultural demand shifted to daytime
1 GW battery	Addition of 1 GW, 4 hour duration battery
2 GW battery	Addition of 2 GW, 4 hour duration battery
4 GW battery	Addition of 4 GW, 4 hour duration battery
Combined flexibility	Pumped-storage hydro, coal power plant flexibility, 1 GW battery and agricultural demand response

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Abbreviations and acronyms

APPDCL	Andhra Pradesh Power Generation Development Company Limited
ASEAN	Association of Southeast Asia Nations
CEA	Central Electricity Authority
CEEW	Council on Energy, Environment and Water
CO_2	carbon dioxide
CPUC	California Public Utilities Commission
CSTEP	Center for Study of Science, Technology and Policy
DISCOM	distribution company
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
FY	financial year
GDP	gross domestic product
IEA	International Energy Agency
IEX	India Energy Exchange
ISGF	India Smart Grid Forum
LBNL	Lawrence Berkeley National Laboratory
MIGRATE	Massive InteGRATion of power Electronic devices
MNRE	Ministry of New and Renewable Energy
NITI Aayog	National Institution for Transforming India
NREL	National Renewable Energy Laboratory
POSOCO	Power System Operation Corporation Limited, India
PPA	power purchase agreement
PSH	pumped-storage hydro
PV	photovoltaic
PXIL	Power Exchange India Limited
RUVNL	Rajasthan Urja Vikas Nigam Limited
SDS	Sustainable Development Scenario
SEDM	Solar Energy Data Management
SLDC	state load dispatch centre
STEPS	Stated Policies Scenario
TOU	time-of-use
VRE	variable renewable energy
WEO	World Energy Outlook

Units of measure

g CO_2	gram of carbon dioxide
g CO_2/kWh	grams of carbon dioxide per kilowatt hour
Gt CO_2	gigatonne of carbon dioxide
Gt CO_2/yr	gigatonnes of carbon dioxide per year
GW	gigawatt
GWh	gigawatt hour
GWs	gigawatt second

INR	Indian rupee
kg	kilogramme
kV	kilovolt
kW	kilowatt
kWh	kilowatt hour
MW	megawatt
MWh	megawatt hour
TWh	terawatt hour

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