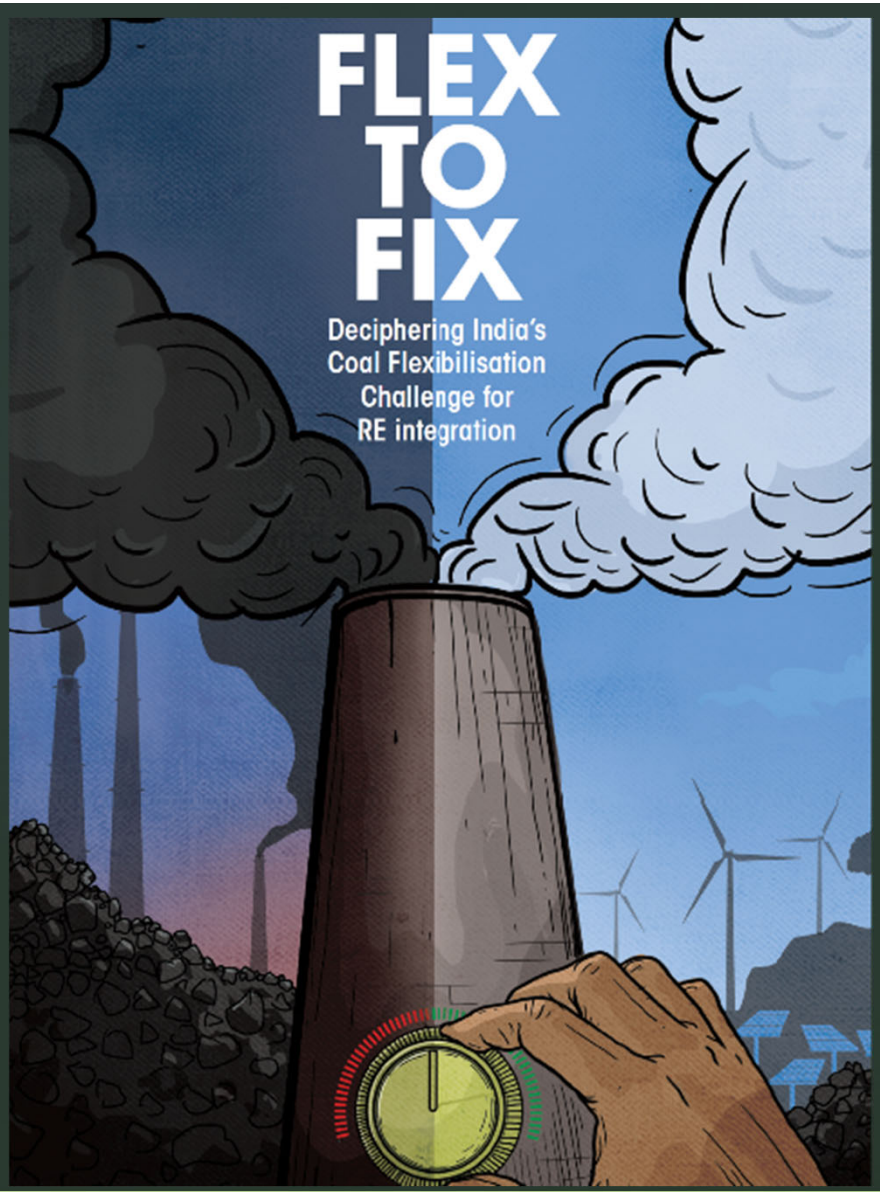
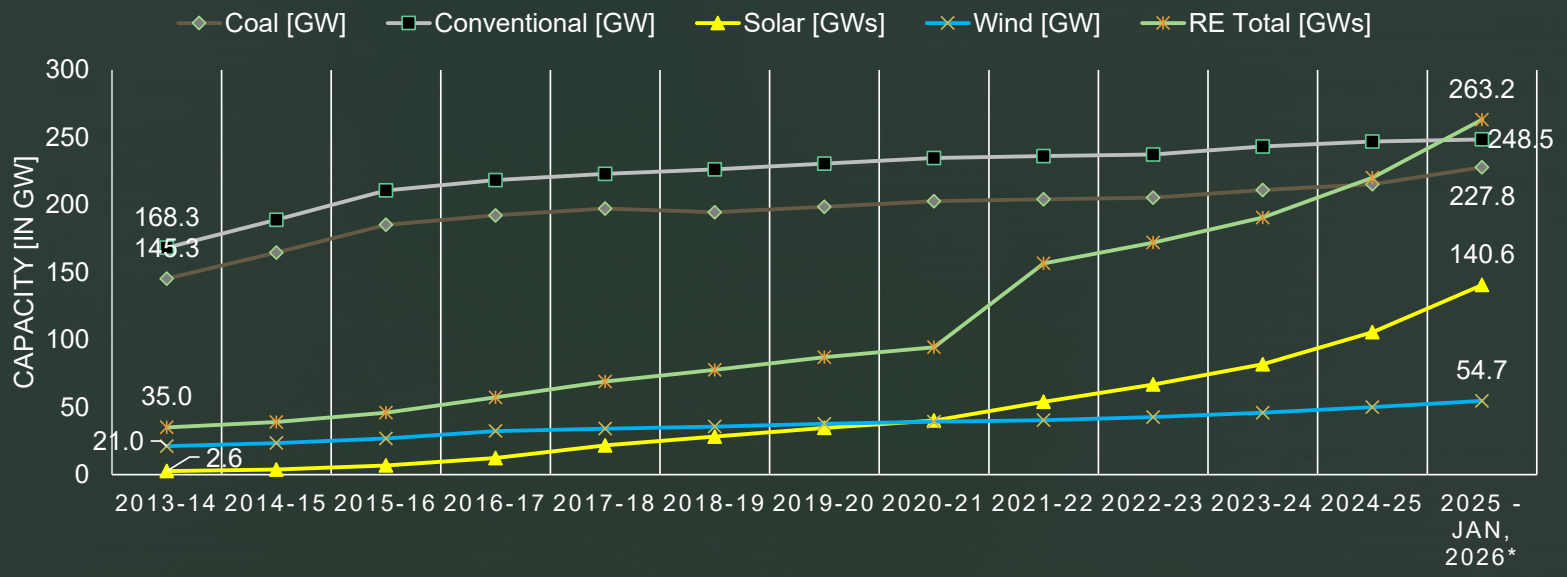


By: **Parth Kumar**
Sustainable Industrialization Unit,
Centre for Science and Environment

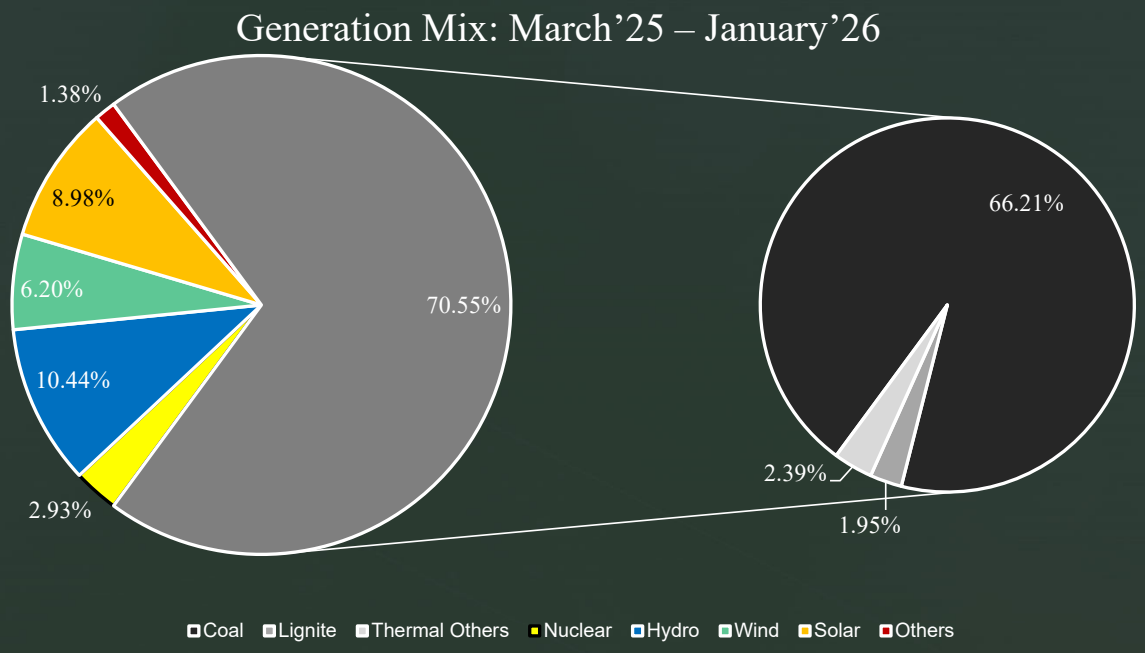
Why the Need for Flexibilization in the Power System?

India's Power Sector: An Evolving System



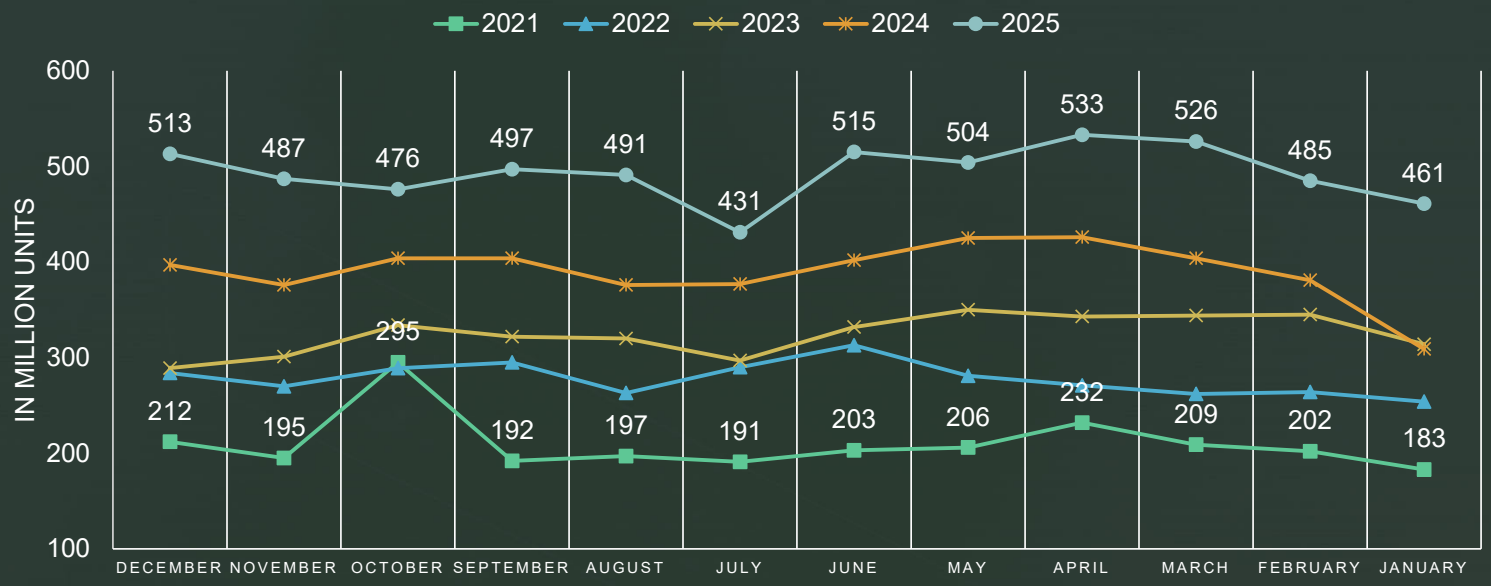
- By 2026, RE has overtaken the share of fossil fuels in the installed capacity , with a further **148.3 GW** of RE under construction.
- India's power sector's fossil capacity is also rising, with **7.2 GW of coal** added in FY 2025-26, and ***37.7 GW under construction***.

India's Power Sector: Coal Still Dominates Generation



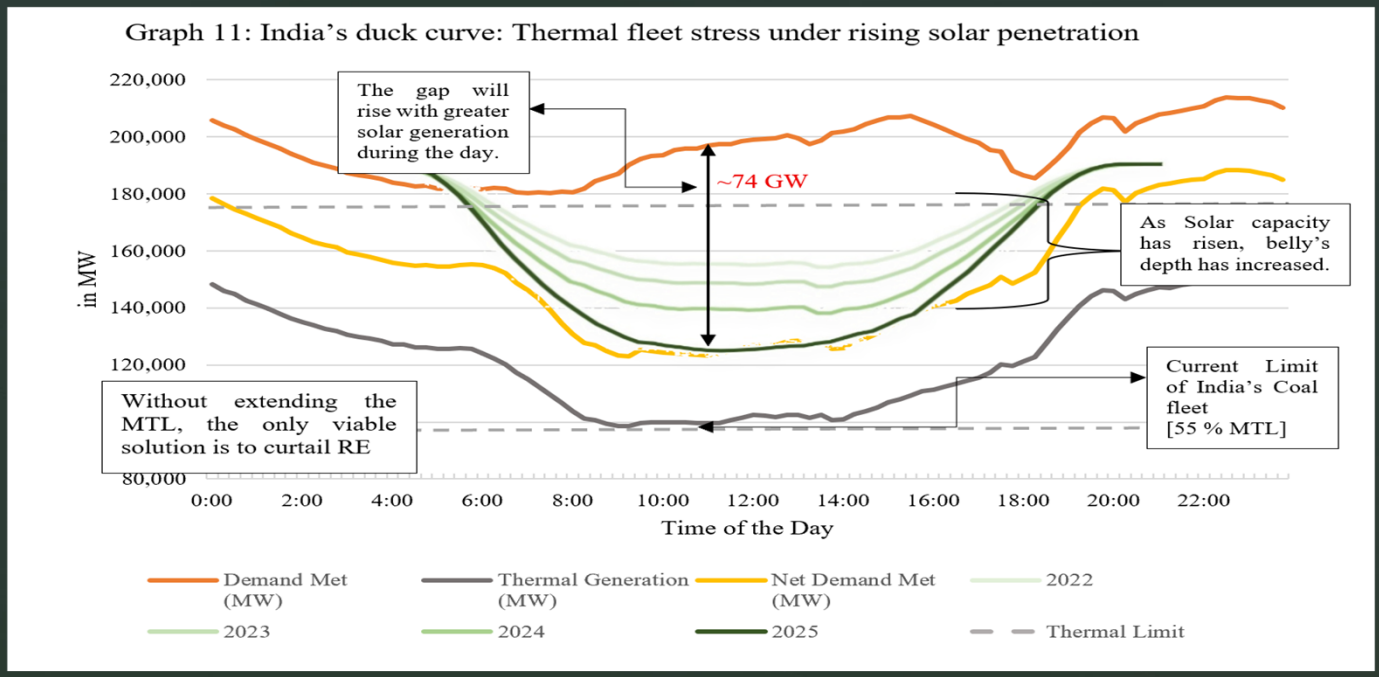
- Despite progress, in FY 2025-26, fossil fuel, primarily coal has dominated the power generation share with 66 percent being supplied by coal.
- This excludes the fuel used by the large industrial sector, that is also coal dominated with usage via Captive power plants.

India's Power Sector: Solar Energy Is Rising



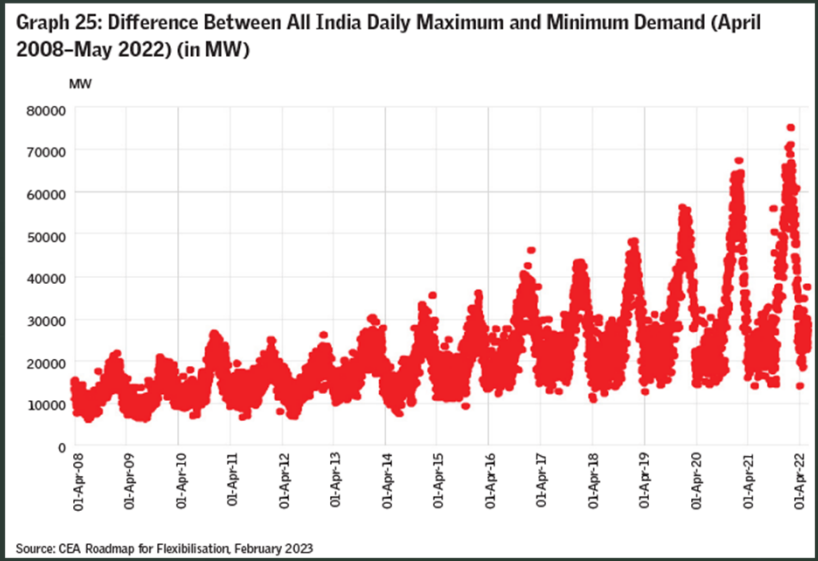
- Year on year, the solar energy penetration is rising in India, the graph is showing the generational peak for the past five years.
- This is impacting the **role of coal based thermal power to move beyond base load** operations, towards flexible resource.
- Solar energy's capacity recording ***3.5 times increase*** **over the past 6 years**, rising from **40 GW in 2020-21 to more than 160 GW in 2026** and almost *100 GW is under-construction*.

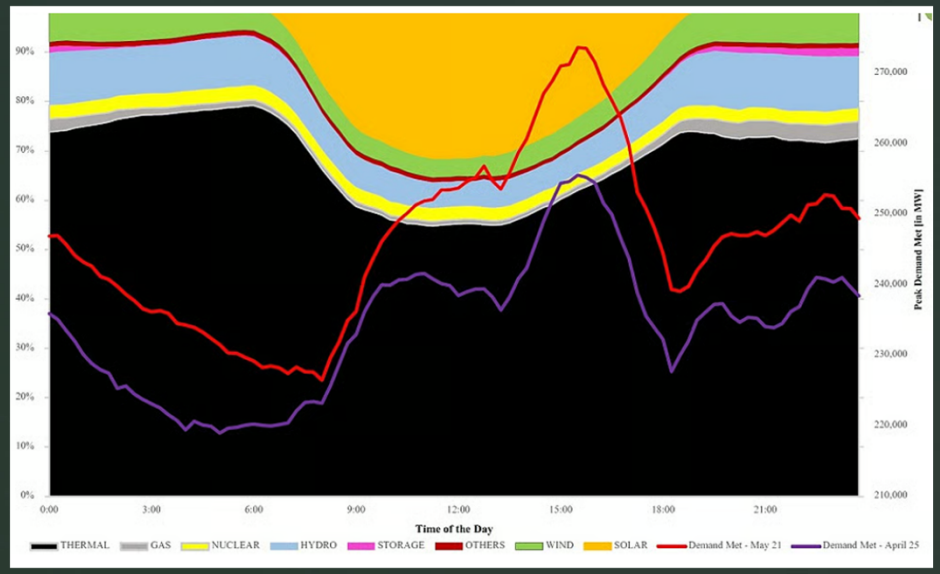
India's Power Sector: Deepening Duck Curve



- The *Y onY* addition of solar energy can be seen via the deepening belly during day-time operations, with thermal operation touching its operational limit. Net load ramp has reached up to 74 GW.
- Any further addition of solar energy requires greater thermal flexibility in operations.

Power Demand: Increasing and Variable

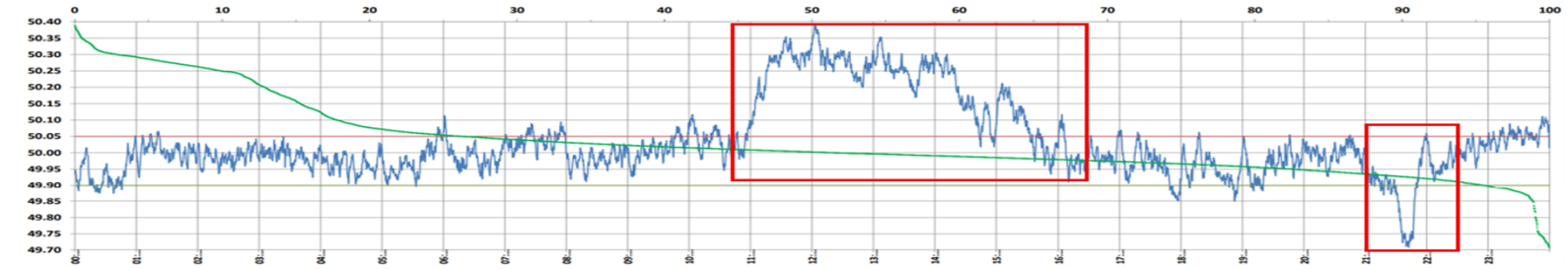




- The variance in minimum and maximum demand in a day gone up from 10-20 GW in 2008 to almost 70GW in 2022.
- Increasing peak demand (273GW peak in June 2026) and its shift towards later hours further enhances the need for coal flexibility.

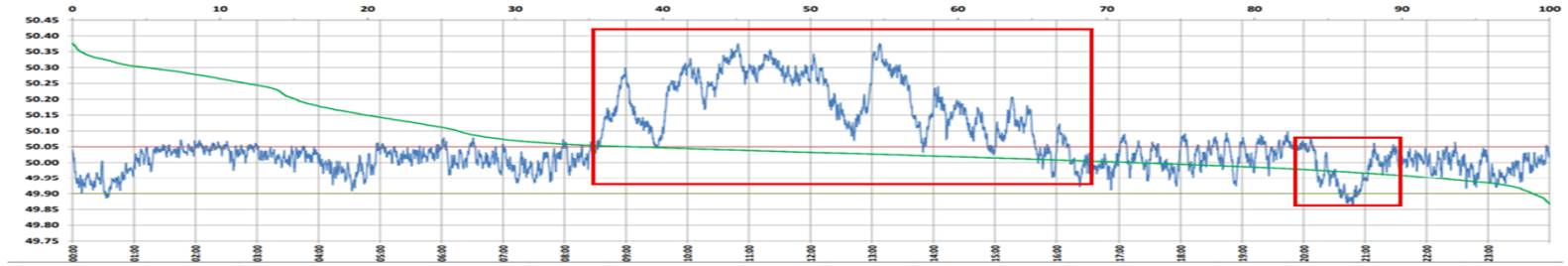
Grid Stability: The Frequency Challenge

Figure 6: Indian GRID - Frequency profile: August 4, 2024



Source: GRID India – Daily Frequency profile report

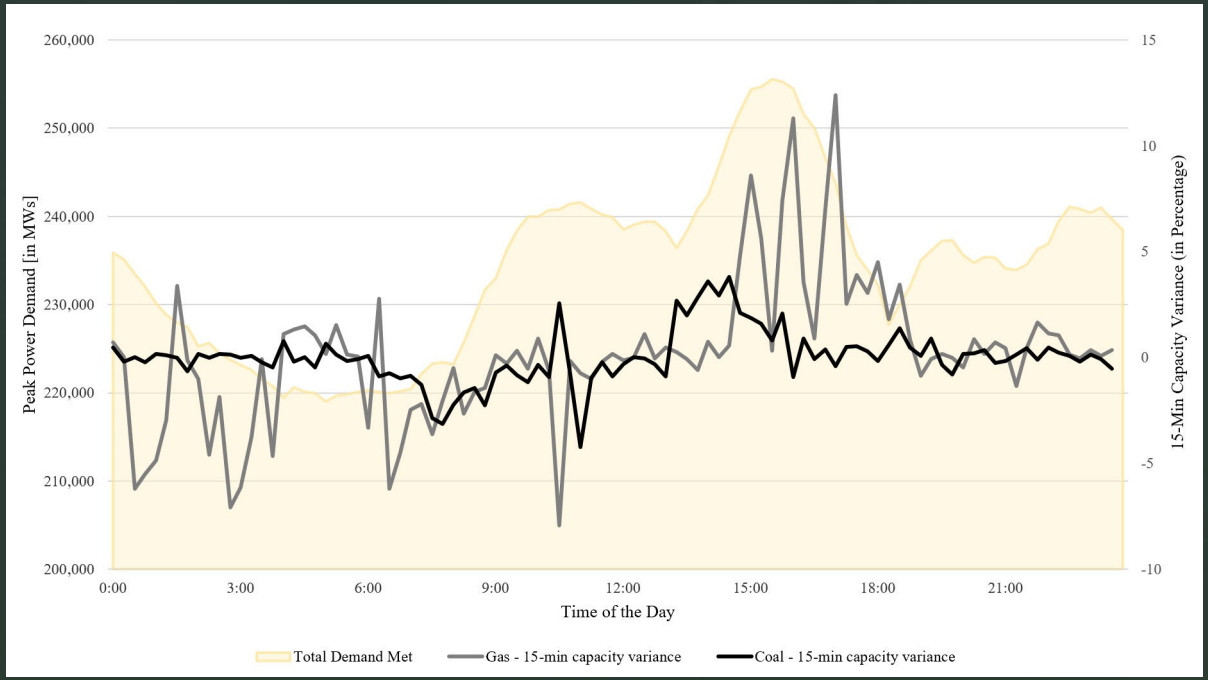
Figure 7: Indian GRID - Frequency profile: August 25, 2024



Source: GRID India – Daily Frequency profile report

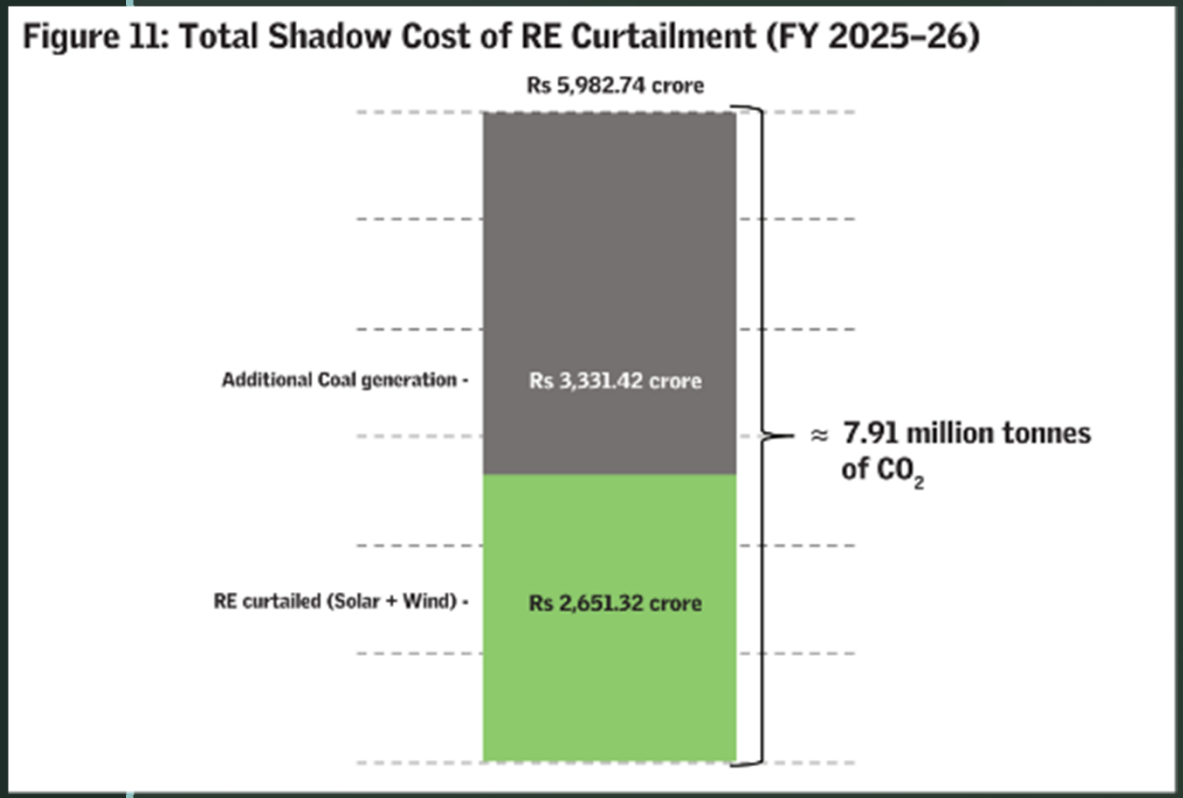
- In India, the NLDC is responsible for maintaining system frequency within a narrow operational band of ***49.9–50.05 Hz***
- With high solar generation, in August 2024, the Indian grid experienced persistent high-frequency operation on multiple days as coal based thermal stations were scheduled below their MTL but continued to over-inject power to remain near technical minimum operation.

Gas: A Costly Alternative



- Gas generation, exhibits sharp and rapid fluctuations, in a 15 minute block.
- Gas fulfils the role of inadequate ramping of coal units. Increasing reliance on high-cost gas generation (~Rs 12/kWh) to meet demand surge, raising system costs, costing three to five times more than coal or solar

RE Curtailment: The Sunk Cost of Curtailment



- In FY 2025-26, ***a cumulative total of 7.62TWh*** (2.54 TWh of generation related curtailment) ***of RE has been curtailed***, amounting to ***1.8 percent*** of the total RE generation or *0.4 percent* of the total electricity generation.

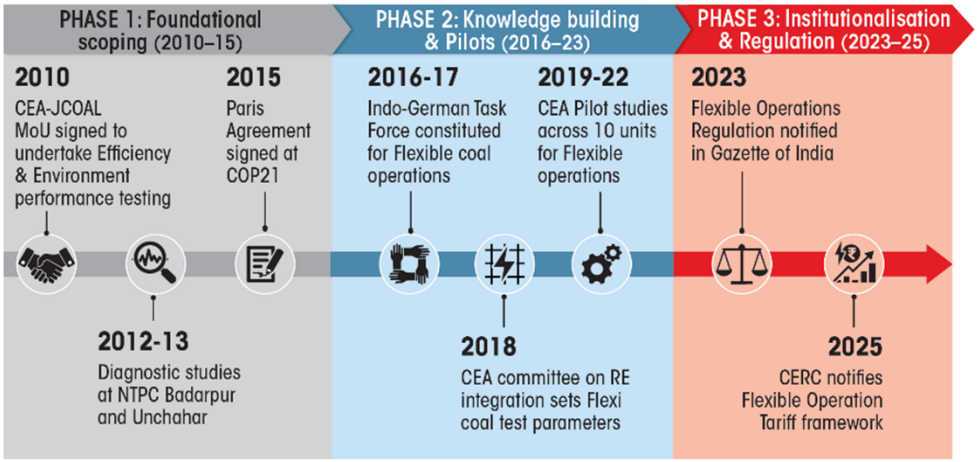
- On a financial level, this amounts to a ***total economic cost of ₹5,982/- Cr / $ 628M***, with ₹2,651/- Cr / $278M being an unused RE payments and ₹3,331/- Cr / $ 350M in coal power payouts.

- The curtailment has resulted in ***7.91 MT of avoidable CO2 emissions*** over the assessed time period.

Policy & Implementation Status

Flexibilisation: Policy timeline and implementation

Figure 2: Timeline of Indian Flexibilisation Policy

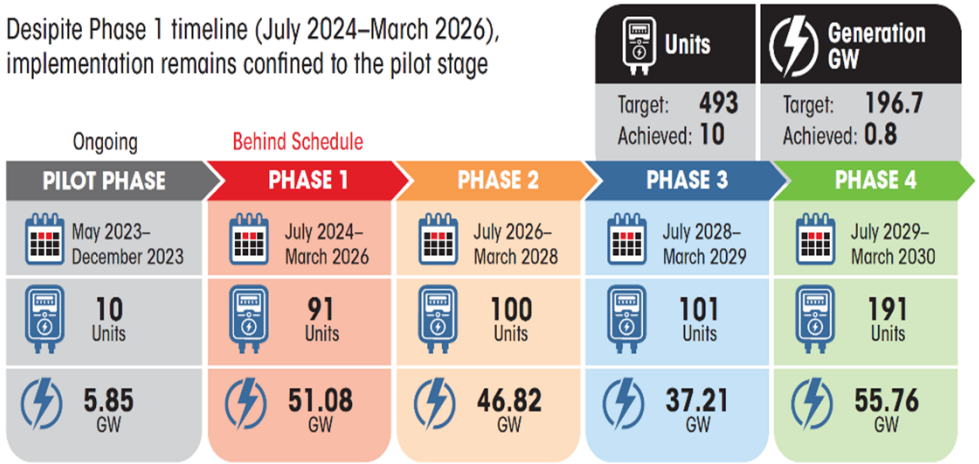


Source: CSE analysis

- Currently, the plan has not moved beyond pilot stage with overall impact of wear and tear unknown or not covered, causing a stall.
- With Phase 1 yet to begin and only 1.9 GW having achieved the 40 percent load target and only 0.5 GW capable of the specified ramping requirements out of the 196.7 GW target under the plan.

- Policy implementation on coal flex began in late *2023* with CERC tariff framework being approved in *July 2025*.
- CEA Phasing plan targets to achieve MTL of 40% and ramp rate between 1 to 3% for 196.7 GW of fleet.

Figure 4: India: Flexibilisation Phasing Plan

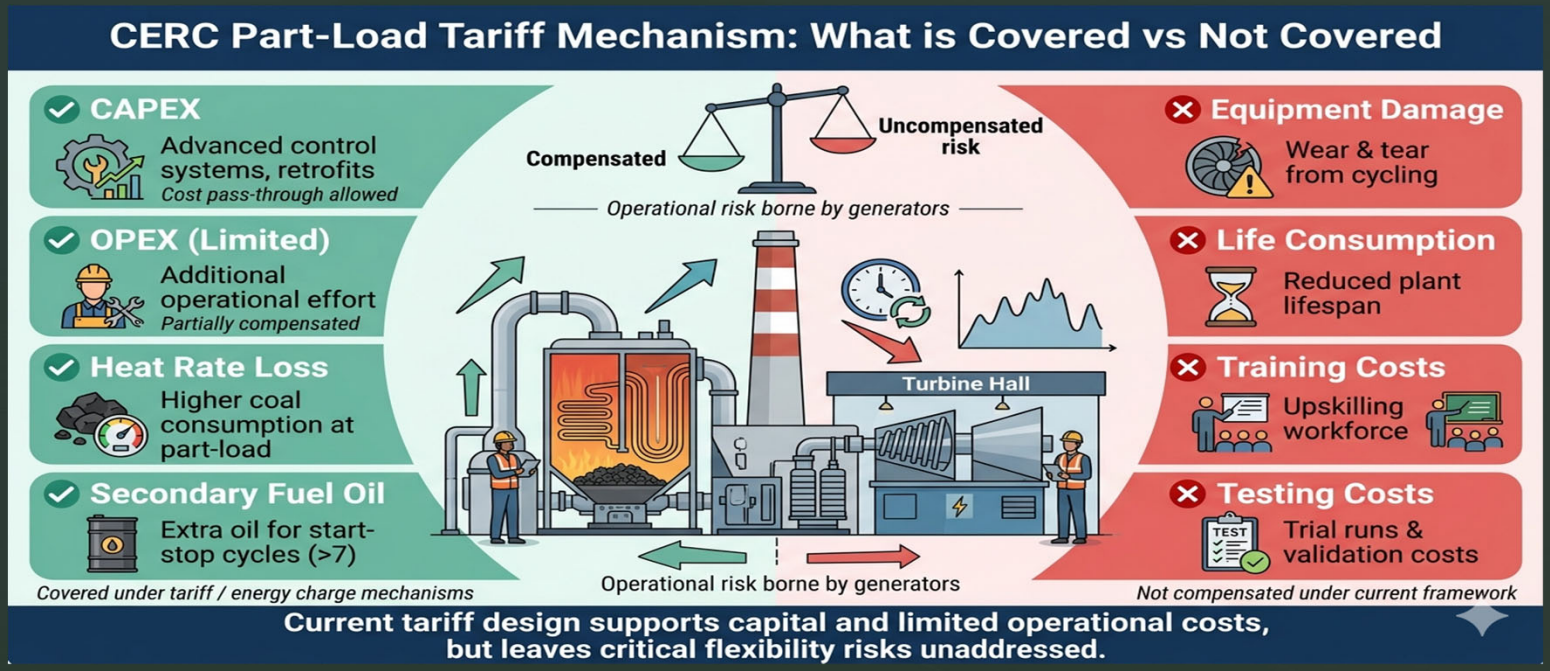


Source: CSE analysis of CEA Phasing Plan, 2023

India's Flexibilization Policy: Tariff Mechanism

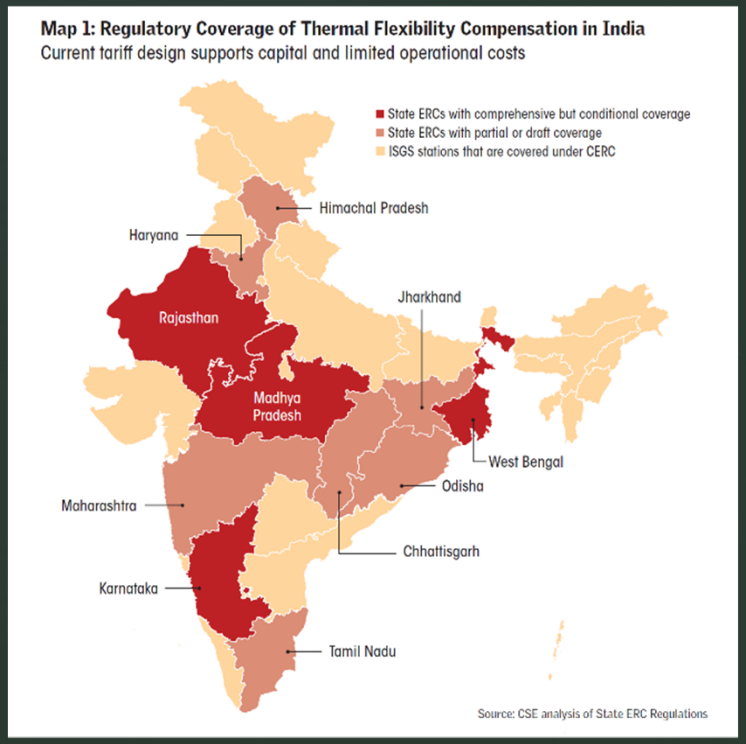
On July 14, 2025,

CERC notified the detailed Tariff mechanism for Flexible operation coverage of India's coal units.



- Expected commercial life of a coal unit is assessed at 25-30 years, and *daily flexible operations will reduce the equipment's useful life and also cause greater OPEX costs*. **A part of it is not covered.**

India's Flexibilization Policy: Story of The States



As of March' 26,

***Majorly 15 states** are yet to be bring any regulatory coverage & compensation.*

***Only 4 have issued notification** with JSERC & TNERC being in draft phase.*

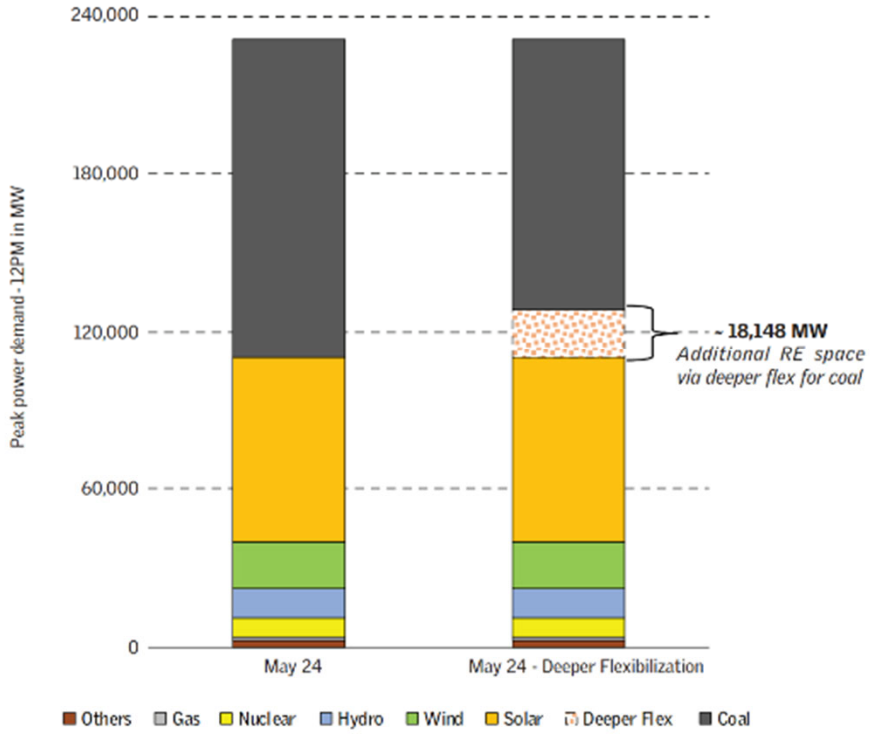
***Rajasthan's** policy seems to be the most advanced in terms of supporting flexible operations.*

- Four Indian states namely, Rajasthan, Madhya Pradesh, Karnataka, and West Bengal, have introduced compensation mechanisms.
- The CERC's policy is nudging states towards implementation in their respective states though the systemic gaps remain for coal units.

The Gains of Coal Flexibilization

Coal Flexibilization: Potential for RE Integration

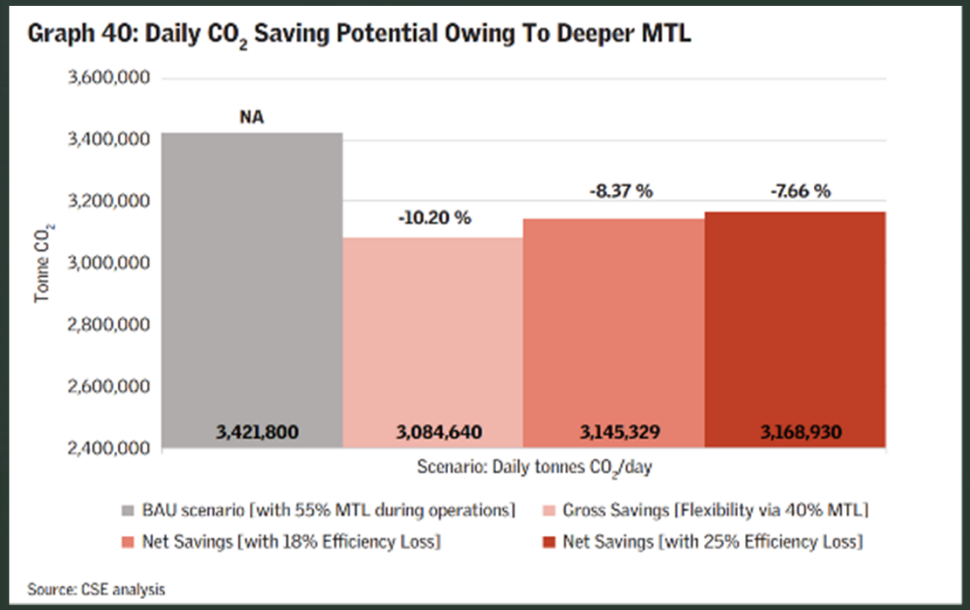
Graph 39: Source-Wise Generation Mix: Actual Operation Vs Deeper Coal Flexibilisation Scenario (May 24, 2026)



Source: CSE analysis of GRID India's Daily PSP Report, May 24, 2026

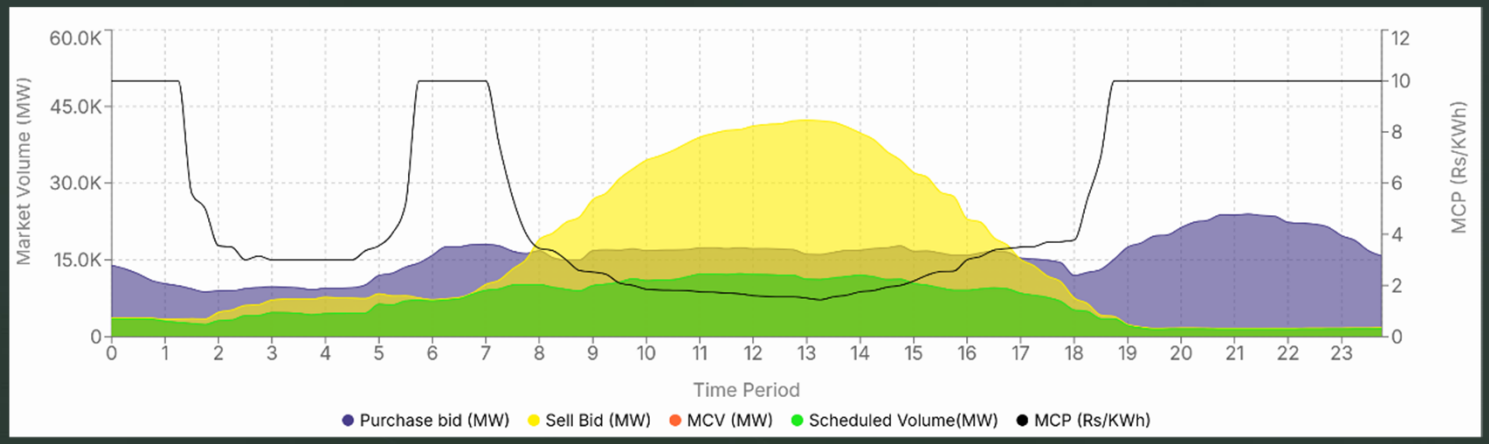
- Currently, doing a 15 percentage reduction in MTL leads to ***34.275 GW or 342.75 GWh*** of RE space on a per day basis.
- ***~125,103.75 GWh or ~125.1 TWh of additional renewable energy***, can be integrated into the power system on an annualized basis.
- On a high demand day such as May 24, ***it would have translated into 18.14 GW additional RE space***, showcasing the potential of Flex.

Coal Flexibilisation: Potential for Emission Reduction



- Similarly, by running less coal, ***there is potential to save CO2 emissions***.
- ***~ 92–101 million tonnes of CO2 annually*** OR ***~ 7.7–8.4 percent net emissions,*** reduction in emissions from the power sector.
- The gains will depend upon actual operational realities, but the assessment is to showcase the potential of the same.

Incentive Opportunities : Role of markets



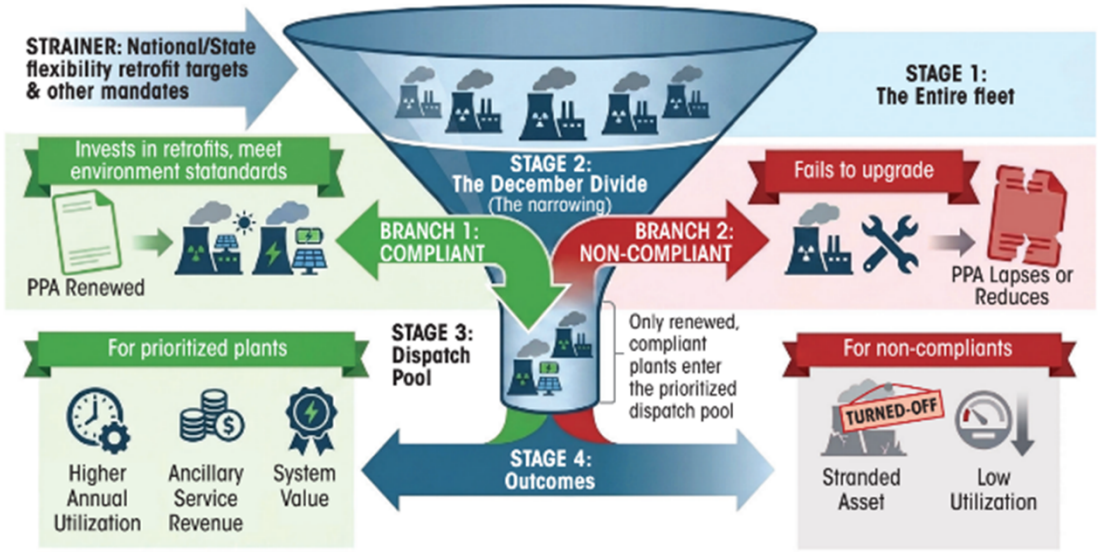
- The GRID faces a shortage of power in the evening, with power prices regularly touching their ceiling of Rs. 10 / kWh.
  - This is an opportunity for flexible power plants to cash in on this by selling power at a higher cost during the evening hours.
  - Operating at lower loads during the day time hours and then assisting the grid in their ramp is key to monetizing this systemic shortage.

International Learnings : China, Germany & Chile

Learnings from other countries: China

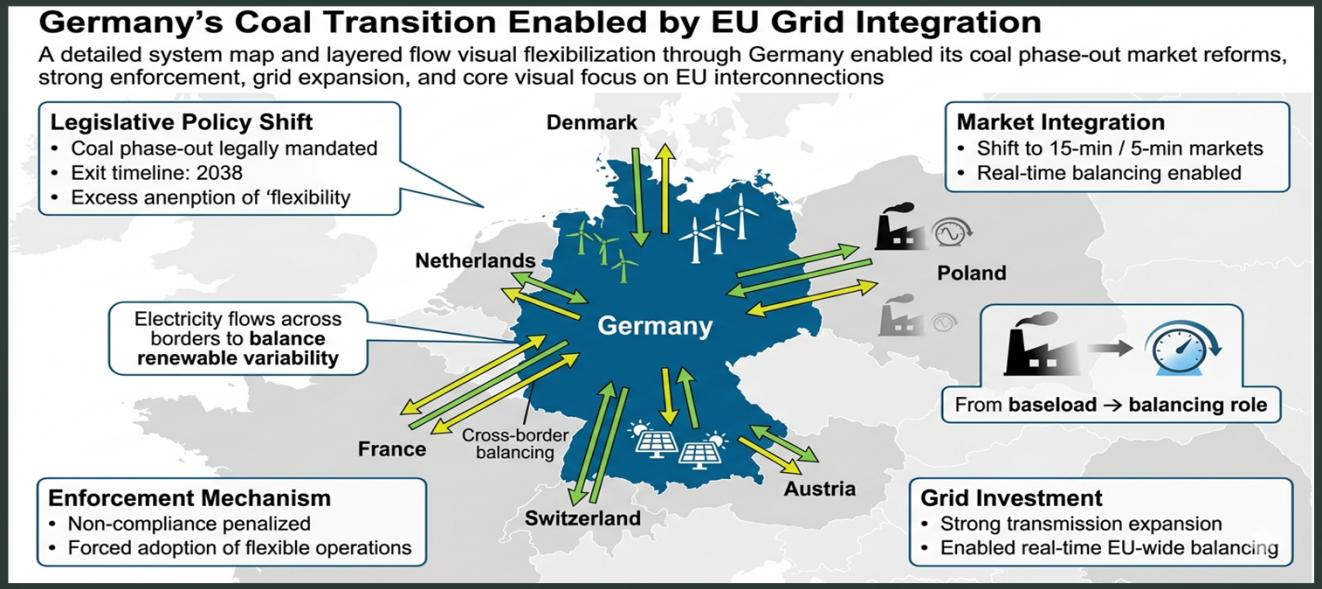
Figure 8: Chinese Policy: Funnel and Strainer System

Survival of the fittest journey for China's annual PPA compliance structure of TPPs.



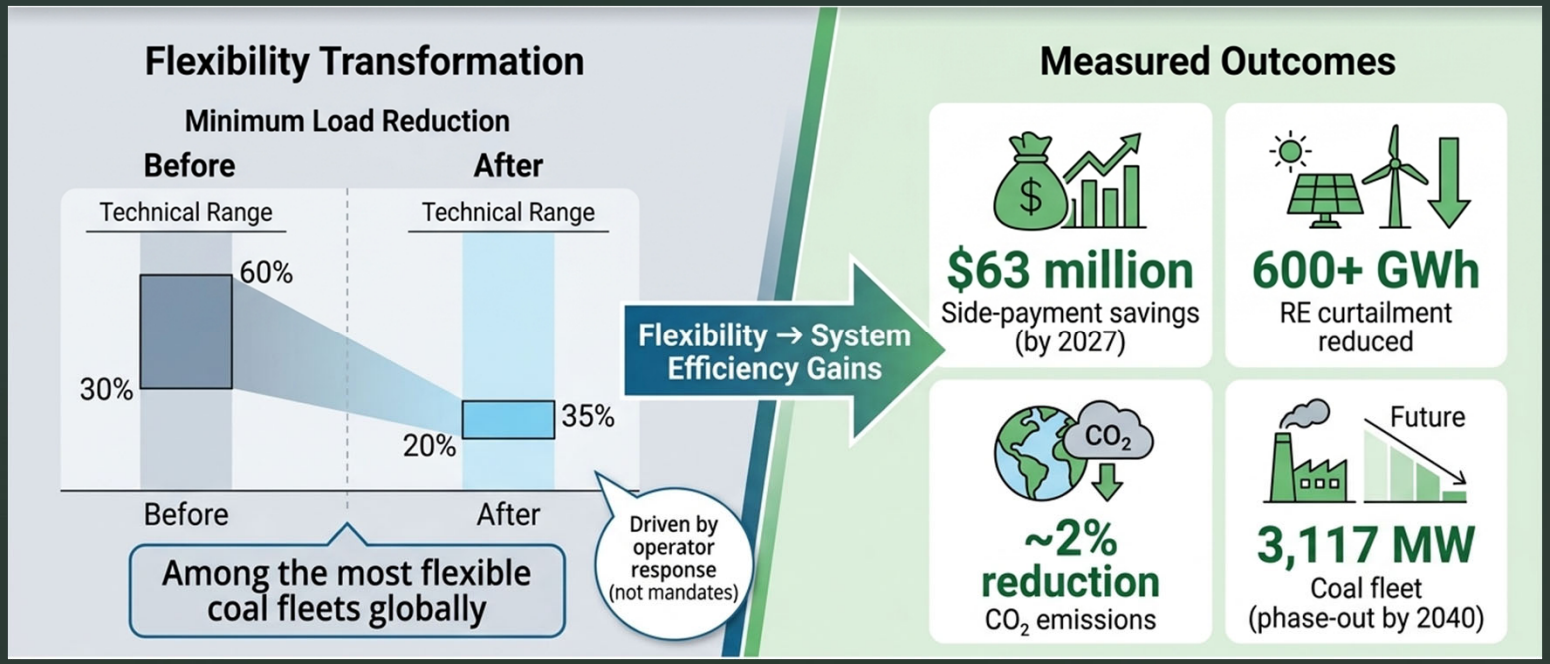
- ***Scale of deployment:*** China started in 2021, has already retrofitted more than 500 GW of its fleet and plans to do 700 GW by 2027 out of its 1.2 TW of coal fleet. The retrofitted fleet is capable of operating between 40 to 25 percent minimum technical load.
- ***Capacity Payment Mechanism to support flexible operations*:** Brought in since 2023 and now updated in 2026, China's capacity payment mechanism will recover at least 50% of coal plants' standard fixed costs, providing revenue support as plants take on a greater capacity and flexibility role
- ***Annual contract system & dispatch preferences***: Non complying units are removed from generation contracts for the year or pushed back in dispatch priority, creating a clear mandate to comply.

Learnings from other countries: **Germany**



- ***Legislative policy shift:*** Germany legally mandated a transition away from coal by 2038 being the deadline to exit.
- ***Rewarding flexibility through markets***: Germany's short-term and intraday market system, let generators adjust output closer to real time, creating value for flexibility as demand and renewable generation change.
- ***Market Penalized non flexibility*:** Inflexible generation increasingly faced the economic consequences of operating against strong market price signals unlike India's capped power market.
- *Targeted GRID investment*: Invested in grid expansion which enabled real time balancing of RE across regions.

Learnings from other countries: Chile



- ***Operational pressure, no major policy incentives*:** Increased RE penetration & Reduction in minimum load raised maintenance costs and failure rates, leading to self initiatives by private operators to get flexible.
- ***Recorded financial and emission gains***: *Flexibilization implementation has translated into savings of about US$63 million in side-payment avoidance by 2027, with RE curtailment reductions of over 600 GWh and **CO2 emissions lowered by nearly 2 percent.***

The Cost of Flexibilisation

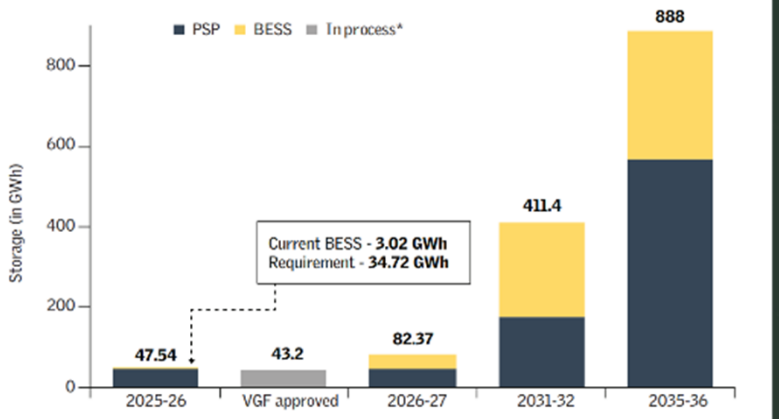
The Cost of Flexibilisation

	Total Costs/Investment	Normalised cost	Tarif Impact	Cost Recovery Duration
Coal Flexibilsation (Capex)	3,078 to 15,390 Cr	6 to 30 Cr / plant	0.47 to 2.35 paise/kWh	5 years
Coal Flexibilsation (Opex)	26.5 to 46.2 Cr/ day (8 to 15% increase)		24.9 to 43.4 paise/kWh	Per day increase
Total			27.25 to 45.75 paise/kWh	
BESS in Thermal (4 hrs)	1.08 to 1.39 lakh crore	8,750 to 11,250 /GWh	Rs. 0.8 to 1/kWh	15 years
BESS in Thermal (7 hrs)	3.7 to 9.6 lakh crore	19,930 to 51,820 /GWh	Upto Rs. 7.1 /kWh	15 years
BESS in Thermal (7 hrs) projected	4.1 to 6 lakh crore	22,100 to 32,430 /GWh	Rs. 3 to 4.5 / kWh	15 years

- Coal flex : Currently much lower capex, Shorter cost recovery period and longer hours of flexibility in a swiftly varying demand scenario.

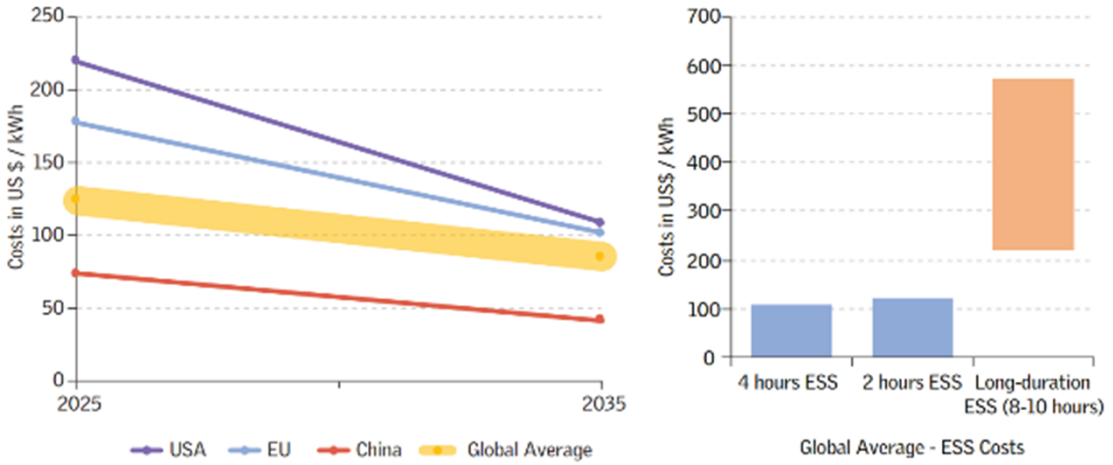
Alternative Flexibilization: BESS

Graph 37: India – State of BESS: Requirement and Deployment



Source: CSE analysis of multiple official reports

Graph 38: Cost Trends of BESS: India and Global



Source: CSE analysis of multiple official reports

- Currently, India's BESS deployment is miniscule and behind their own target set in 2022-23. Targets 321 Gwh by 2035.
- To be a substitute to coal flexible operations, India will need roughly 30.8 GW of Long duration BESS power capacity, corresponding to about **184.7 GWh of energy storage**.

The Need for Flex: Future Scenarios

The Need for Flex: Future Scenarios

Table 18: Peak Demand Trajectories Over Scenarios (in GW)

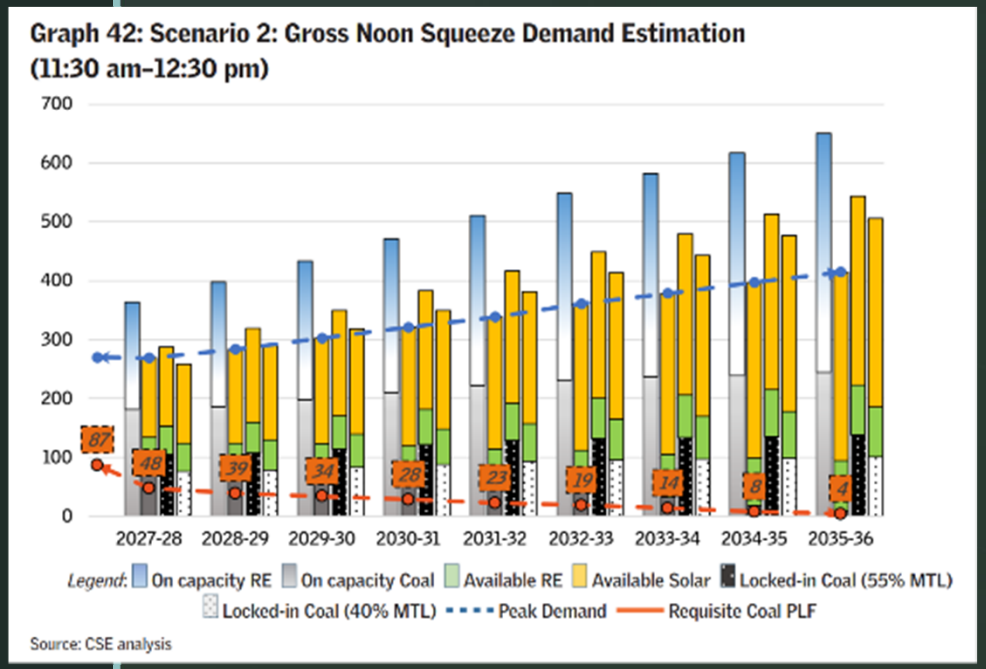
Year	Scenario 1	Scenario 2 & 4	Scenario 3 & 5	*Illustrative scenario*
	Gross Peak Demand (3:30–4:00 pm)	Gross Noon Peak Demand (11:30 am–12:30 pm)	Gross Non-Solar Peak Demand (10:30–11:30 pm)	*High RE + Low Gross Demand (3:30–4:00 pm)*
2027-28	289	268.77	268.77	*236.98*
2028-29	305	283.65	283.65	*250.10*
2029-30	325	302.25	302.25	*266.50*
2030-31	345	320.85	320.85	*282.90*
2031-32	364	338.52	338.52	*298.48*
2032-33	388	360.84	360.84	*318.16*
2033-34	407	378.51	378.51	*333.74*
2034-35	427	397.11	397.11	*350.14*
2035-36	446	414.78	414.78	*365.72*

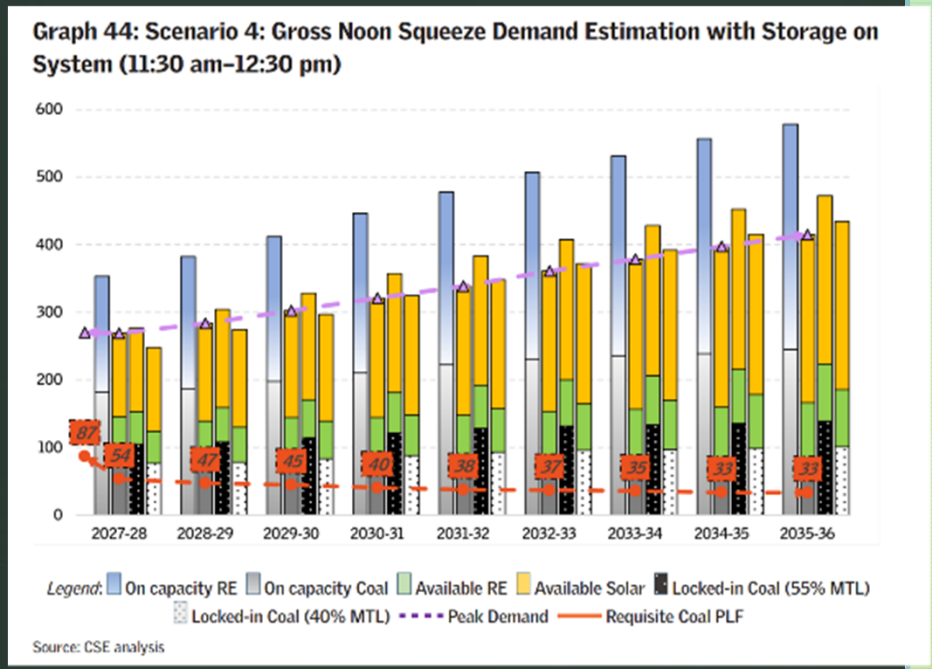
Source: CSE analysis of CEA Long-Term National Resource Adequacy Plan (2026-27 to 2035-36)

- The scenarios aim to explicitly isolate the structural rigidity of the coal fleet, while showcasing the need of Flex in our power planning.
- The models are built upon the National Resource Adequacy plan of CEA.
- We have isolated the model to peak demand days during high RE as is the case during summers in India.

**The model will not hold true during lower RE generation days. It has not accounted generation of other sources beyond Coal, Solar, other RE and storage.*

The Need for Flex: Future Scenarios





- Graph 1 - During daytime, when peak is lower on average, RE is high, with no storage, the curtailment numbers are sure to rise extensively.
- Graph 2 - Even with the targeted storage capacity, the coal plants will need to go below 40% 2030 onwards to prevent RE curtailment.

Coal Flexibilization: Key Challenges & Recommendations for Implementation

Coal Flexibilization: Key challenges

- ***Lack of a level playing field:*** Some players have taken initiatives and some haven't even moved ,resulting into a first mover disadvantage scenario.
- ***Debate around impacts of flex on a heterogeneous fleet***: Scale of impacts of low load operation across technologies ,31 different unit sizes, new to 50-year-old age profiles is a constant topic of debate, speculation & discussion.
- ***Incomplete Tariff coverage***: All elements of flexible operations are not covered within the central and state compensation mechanisms. A large part of state fleet yet not covered.
- ***No additional incentives or disincentives to drive implementation***: Apart from partial compensation, no preference in dispatch, limited market based incentives & no disincentive for non compliance.
- ***Unfunded Pilot and Upskilling Costs***: Testing, validation runs, and workforce familiarisation are necessary to transition toward flexible operation, yet these preparatory expenditures are not covered.
- ***Fuel Quality Gaps:*** Fuel complicates operational flexibility, with India's high ash content fuel and poor fuel supply management at unit level.
- ***Workforce Capability Gaps at GRID and TPPs:*** Flexible operation, especially during ramping, demands greater manpower and continuous monitoring, thus creating a greater human cost.
- ***Legal complications to transition***: Moving out of contracts around Fuel supply, current PPA structures don't consider flex challenges, reduced usage can raise dispute risks for DISCOMs.

Coal Flexibilization: Way ahead

- ***Baseline unit health study***: To determine uncovered tariffs and to better strategize implementation of the phasing plan
- ***Consideration of factors for phasing plan***: Actual heat rate and emission impacts, greater utilisation of low emission assets, considering 2 shift operations.
- ***Comprehensive tariff coverage***: A tariff that covers life costs, equipment damage costs, testing periods and training costs
- ***Expansion of tariff coverage and alignment in States***: To expand in remaining states, create a level playing field with similar obligations for state and private units as well
- ***Incentivise flexibility***: Beyond compensation, establish incentives like preference in Merit Order Dispatch or lump-sum payouts, time of day tariffs, market based incentives for units that achieve flexibility targets

Coal Flexibilization: Way ahead

- ***Provide testing windows***: GRID & LDCs should provide designated scheduling windows and transmission headroom for ramp testing and workforce familiarization.
- ***Building Workforce and System Capability***: TPPs upskill plant operators, strengthen maintenance, fuel management & GRID and LDCs need to strengthen **real-time** monitoring, simulation, forecasting and operator training to manage a more dynamic grid.
- ***Reforming FSAs & PPAs:*** FSAs and PPAs need to reform to adjust low operation loads and ensure fuel quality
- ***RE curtailment cost disclosure***: A uniform RE curtailment cost disclosure is necessary to highlight the issue at the system level and create necessary nudge.
- ***SOP to mitigate local air pollution*****:** Flexible operations result in greater coal consumption, raising an environmental challenge, thus unit level SOP is necessary

Thank you!

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