Market Design: India's Path to a Low Cost, Low Carbon Electricity System

Taking the next steps to decarbonised power

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***Abstract*—India can integrate high capacities of wind and solar generation, 390GW by 2030, well exceeding policy targets without raising costs. But a grid dominated by the efficient use of renewables and existing powerplant can only be achieved with a radical approach to market incentives.**

Keywords-component; renewables, solar, wind, flexibility, market design

I. Introduction

India's deployment of wind and solar has surged in recent years thanks to ambitious government targets and dramatic cost declines that have made variable renewable sources competitive with coal capacity. But without policy intervention and new market design, India's clean electricity future may struggle to achieve its potential.

In our paper *Developing a roadmap to a flexible, low-carbon Indian electricity system*[1], CPI Energy Finance explores how these ambitious targets may be met through an integrated approach to flexibility which combines demand side management, energy storage technologies and more flexible use of India's powerplant capacity

Since that report was published, we have initiated a two-year program to develop a roadmap to help achieve broader market reform across India. This work supports the ongoing agenda of electricity market reform that runs in parallel to the work carried out by national organizations such as the Central Electricity Regulatory Commission and the Power System Operation Corporation. We are also working directly at the state level in Karnataka, Maharashtra and Tamil Nadu in order to find solutions to the challenges faced by distribution companies, load dispatchers and regulators.

This work will explore the range of existing and emerging options in India to improve access to thermal flexible capacity and incentivize investment in low carbon flexible resources, specifically demand response and energy storage.

II. Approach and Methodology

Data for this project was collected from primary sources such as interviews with stakeholders and secondary sources such as historic demand data from POSOCO. This data was analyzed using spreadsheet-based mathematical models to calculate the cost, potential and options required to address India's electricity system flexibility needs under different scenarios.

Three scenarios are considered based upon the work of the Energy Transitions Commission India (ETC India) and The Energy Resources Institute India (TERI) in evaluating the changes to India's electricity supply and demand between now and 2030: A *current trajectory scenario* based on forecasts of future renewable energy deployment following current trends; a *current policy scenario* where India meets the government's current renewable energy targets; and a *high renewable energy scenario* that maximizes renewable energy by 2030 with no new coal additions beyond the country's current pipeline.

The analysis looks at three different flexibility options namely *demand flexibility* (utilizes various demand side options), *powerplant flexibility* (utilizes the flexibility potential of existing and planned powerplants), *energy storage* as well as combinations of all three. We then modelled the economically optimum flexibility mix to meet the different flexibility needs namely, *short-term reserves*, *ramping requirements*, *daily balancing* and *seasonal balancing.*

By ranking flexibility resources, supply curves were created to show the costs of dispatch to serve each need. These supply curves and forecasts for annual hourly load shapes were used to evaluate "dispatch" for different portfolios of flexibility options to meet the various flexibility needs of the system. The aim was to both assess the cost of integrating various levels of renewable energy into the system, as well as to evaluate how the availability of different supply side options affects cost and overall dispatch. Thus, we have used our model to understand the costs and dispatch of the Indian system for each of the three energy mix scenarios outlined above.

[1] CPI Energy Finance report published https://climatepolicyinitiative.org/wp-content/uploads/2019/02/CPI-India-Flexibility-February-2019.pdf

Much of our analysis assumed India as a single unit. To understand how regional differences could affect flexibility costs and resource requirements, four states with distinct energy needs and resources were studied: *Karnataka; Tamil Nadu; Bihar; Uttar Pradesh.* Regions were evaluated separately, and then in the context of how each state/region could benefit from or be affected by the trading of flexibility resources. The state differences provide initial indications of the needs for interregional/ multi-regional trading and national level policy.

Finally, based on the portfolio analysis and the regional analyses, we identified the key factors and policies that will be needed to create a more reliable, affordable and low carbon system.

III. Addressing India's Renewable ambitions

A. Renewable integration: a flexible solution

India can successfully integrate 390GW of wind and solar generation by 2030, an increase of more than 40% above the current renewable energy trajectory, at a total system cost that is lower than that of the current trajectory. By making both electricity supply and electricity demand more flexible, India can achieve these higher levels of clean energy, creating a modern, low cost energy system, while reducing carbon emissions. Working with the Energy Transitions Commission India (ETC India), Climate Policy Initiative Energy Finance (CPI EF) has found that ample technology and system concepts exist to create the flexibility required to build and operate a reliable, low cost, low carbon system, but implementation is among the biggest challenges facing the energy transition in India. Increasing flexibility needs can be met cost effectively using a combination of investment, incentives and technologies that:

1. Influence demand patterns by changing how and when consumers use energy;
2. Increase the flexibility of existing thermal power generating stations;
3. Encourage development of new energy storage options and domestic value chains.

B. India must address several flexibility needs, each of which will grow under any scenario

Modern electricity systems must balance electricity demand and supply at every instant, and at every location, to avoid outages and damaging swings in voltage and frequency. Adding supplies whose output depends on gusting wind levels, or fades as the sun sets, increases the difficulty of making this continuous match. To make a continuous match of supply and demand, system operators must:

- **Reserve** some generation capacity within the system to replace energy lost if a powerplant or transmission line suddenly fails, or to meet an unexpected surge in demand.
- **Ramp** (increase/decrease) output fast enough to meet expected sharp shifts in demand, such as when the sun sets and consumers turn their lights on at once.
- **Balance daily** demand and supply over the course of each day, for example, balancing higher power demand in the late evenings against higher solar energy production in the middle of a sunny day.
- **Balance seasonal** supply and demand to meet annual cycles, for instance, when rainy, sunny or windy days drive up energy supply while energy demand is driven by commodity demand cycles.

Figure 1: Growth in key flexibility needs

In figure 1 above, the three bars for each of the flexibility needs represent the three scenarios we use in the analysis: a current trajectory scenario[2]; a current policy scenario; and a high renewable energy scenario, respectively from left to right. Flexibility needs increase significantly in all three scenarios, indicating that improving system flexibility should be a priority, regardless of the level of India's clean energy ambitions.

C. India will need to develop new types of flexibility to meet growing needs

Historically, India has relied on thermal and hydro powerplants to balance supply with demand, turning these plants up or down in response to varying demand. When flexibility demands were too high for the powerplants to cover, power quality dipped and outages were forced across the system. In recent years, India has reduced unplanned outages, where system operators have planned reduced service and curtailments to groups of customers in order to improve power quality. Responding to planned service interruptions is also less costly to consumers than unexpected interruptions. Meanwhile, consumers have assumed that supply would adapt to their consumption patterns. Even though small changes in their consumption patterns could significantly reduce total system costs, consumers have been given little or no information and incentives to shift their demand to meet supply. Powerplants, for their part, have options that would significantly increase the amount of flexibility they can offer to the system, but they also lack incentives to cover capital costs and higher operating costs of providing this flexibility, even though the lower system costs would more than make up for their higher costs. Meanwhile, the cost of energy storage, including batteries, is falling rapidly, while the capability is increasing.

[2] Exploring Electricity Supply Mix Scenarios to 2030: Scenario Framework (TERI).

All three of these flexibility options need to be pursued for India. Developing all three enables the lowest total system cost and offers backup to the system in case one or another of them develops less slowly than forecast. Integrating these options to achieve the lowest cost and most reliable supply is an important task both in balancing the development effort between the options, and in developing systems that incentivize and dispatch these resources.

D. Integrating these flexibility options is the key to keeping costs low

To assess this balance and estimate the cost of integrating higher levels of renewable energy on the system, CPI has developed a series of supply curves for each of the four flexibility needs, and some important variations of each type of flexibility. These supply curves are based upon a series of models where CPI has estimated the cost, including capital and financing costs, operating and fuel costs, not factored in, and energy losses (each where applicable). This cost, when allocated to the kWh shifted over the course of the day, is represented by the height of the bar in figure 3 below. The width of the bar represents our estimate of the potential that could be available in India by 2030 and is based on conservative estimates of ownership of equipment and the share of that equipment that could be made available for offering the service.

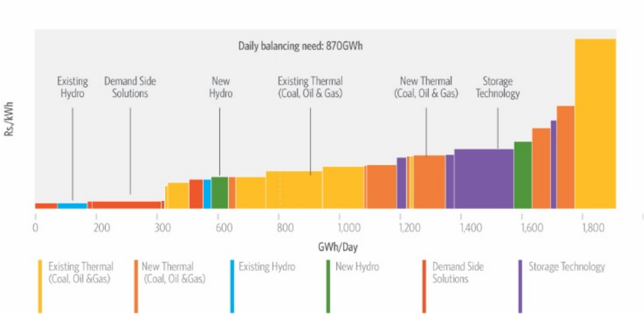

Figure 2: 2030 supply and demand for daily balancing (on an average day for 6 hours of energy shift)

Figure 2 shows an example of an average day of daily shifting. Note how demand measures and existing hydro provide the cheapest means of meeting this particular need, but existing powerplants will also be required, including some increase in flexibility of existing plants. If demand side management and new hydro are not developed successfully, newer powerplants and batteries might be needed. Another perspective would be to look at how generation profiles and renewable energy curtailment[2] affect the dispatch of powerplant across a day, week or year. Figure 4 on the following page shows output from our model of how the mix of flexibility options affects powerplant operation and curtailment. The dark line near the top shows demand across a week.

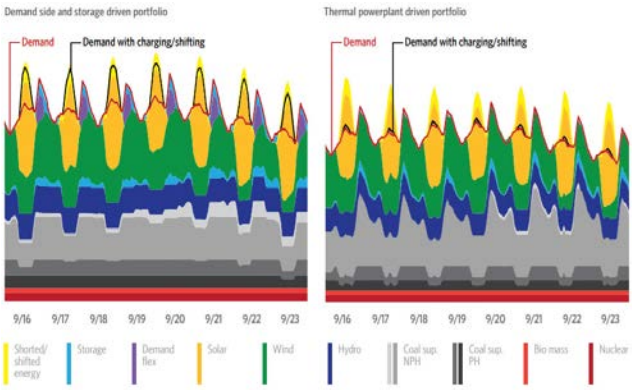

Figure 3: Demand flexibility and storage allow thermal plant to operate more efficiently

In the left-hand graph of figure 3, where demand flexibility and storage are included, thermal powerplants operate much more steadily, which increases their efficiency. On the right, without demand flexibility and new storage, powerplants are more strained and more energy – the energy above the lines – is curtailed/wasted. Our analysis shows that the mixed portfolio has 82% to 97% less energy wasted, 5% to 8% lower total system costs, and 8% to 12% lower total carbon emissions.

E. A mixed portfolio of flexibilty resources is the lowest cost option

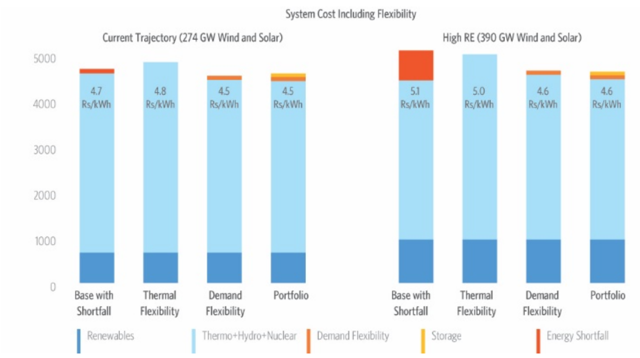

Figure 4: 2030 supply and demand for daily balancing (on an average day for 6 hours of energy shift)

Figure 4 above shows further detail on the cost simulation runs for the complete system, including a breakdown of renewable energy costs (both capital and operating costs), powerplant costs, the costs of demand flexibility and storage, and, in red, the cost of energy shortfalls that would be met by diesel generation.

For both scenarios shown in figure 4, current trajectory and high RE, we have modelled average total system costs (in today’s money), for different portfolios of flexibility options.

- Base option includes flexibility as it is used today;
- In Thermal flexibility option, system flexibility needs are met through powerplant dispatch but would need

investments to increase the flexibility of existing powerplants;
- Demand portfolio relies primarily on demand flexibility, but also uses existing thermal flexibility to balance the overall system;
- Portfolio approach uses thermal flexibility, demand side options as well as storage and results in the lowest cost mix of all three options.

The average system cost for the High RE case is below the current trajectory costs with either the base flexibility, or the enhanced powerplant flexibility. Also, added demand flexibility and storage reduce costs, even at relatively modest renewable energy ambitions. Finally, note that base levels of flexibility lead to energy outages in either scenario, even though enough energy is produced in these scenarios to meet demand.

F. The needs and challenges will be different in different regions across India

The analysis in figures 3 and 4 treats Indian electricity supply and demand as a single unit, unhindered by transmission costs or constraints. The reality is different as India is a large and diverse country with significant transmission costs and constraints. An important consideration in developing a flexible Indian electricity system is a tradeoff between building additional local flexibility or building transmission to harness excess flexibility in one region to use in another. Local flexibility can involve building batteries or prioritising demand side or powerplant options in one area, whereas pan-India flexibility might enable balancing loads between regions with disparate needs.

For example, regions with excess generation during the monsoon season may balance those that have excess solar production at different times of the year.

A complete evaluation of transmission requirements would require detailed assessment of demand and powerplant options in each state and an India-wide transmission model to forecast costs and constraints. This analysis is beyond the scope of this study, but given the range of uncertainties in the estimates of option availability in 2030, it is unlikely that the detailed analysis would provide a great deal of valuable insight. Instead, we have investigated the flexibility needs of four individual states – with different electricity supply and consumption characteristics and flexibility needs – to ascertain how limiting interstate exchange of flexibility might affect the results, and to evaluate how transmission planning and interstate exchanges and markets should be incorporated into a dedicated flexibility development policy. In isolation, some Indian states will face greater flexibility needs than India as a whole, while others will face less. High renewable energy states will often face particular challenges, whereas thermal generation heavy states could have an opportunity to reduce their electricity costs by harnessing and exporting demand flexibility.

CPI looked at four states with different mixes of energy:

Tamil Nadu where wind is already close to 30% of the capacity mix faces seasonal balancing challenges. By 2026/27, nuclear and renewable generation at approximately 42GW are expected to outstrip demand during the monsoon season. In the absence of flexibility measures the state will face the dual economic impact of curtailment of must-run renewables and compensating thermal generation for capacity not called. Figure 5 shows how by 2030 the residual demand after renewables and must-run hydro, which must be met mainly by thermal generation, falls to 1% in the lowest month of the year. That is, powerplants in Tamil Nadu would be, effectively, completely shut down in the absence of sufficient transmission export capacity. This compares to 30% for India as a whole.

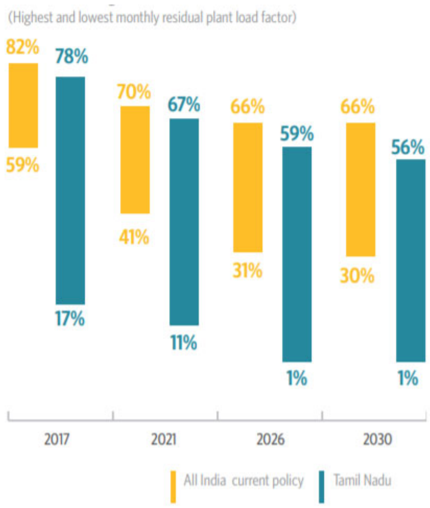

Figure 5: Seasonal balancing need in Tamil Nadu vs India

Karnataka's renewable capacity today represents half of its total; by 2026/27 solar at 18.8GW will make up 40% of its capacity mix. Solar energy output declines rapidly around sunset. Karnataka, with its growing domestic energy consumption, sees its energy demand increasing during those same evening hours. The result is that the rate at which the thermal and hydro power would need to increase – that is the ramp rate – is growing rapidly. As can be seen in Figure 6, by 2030, Karnataka will need to increase its capacity by 30% of its peak demand in just one hour. This figure is double our forecast for India on average. In the absence of flexibility measures, the significant mismatch between the daytime generation and evening peak load will lead to demand for substantial ramping needs of about 11GW.

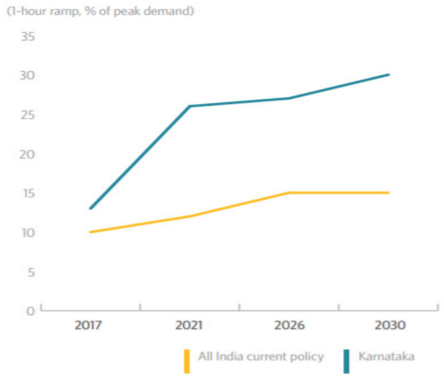

Figure 6: Ramping needs in Karnataka vs India

Uttar Pradesh meets its demand largely through contracted thermal capacity and has relatively lower renewable energy potential. Simultaneously Uttar Pradesh has a relatively well-established industrial base and has a diverse potential for demand flexibility, 12GW spread across AC, agriculture pumping and industry. With access to adequate transmission and distribution infrastructure, the state could look at exporting the flexibility, especially if it is able to harness its demand flexibility potential.

Bihar is a thermal generation heavy state with 4.3GW of contracted capacity faces internal challenges of its power deficit and balancing its own system as demand grows rapidly from a relatively small base. Managing transmission links internally and to other states could help it tap into over 1.5GW of demand flexibility by 2026/27 could contribute substantially in addressing the deficit and also reducing bills.

Figure 7: Growth in flexibility needs and flexibility potential is not evenly distributed

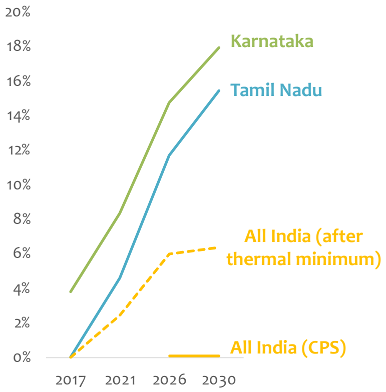

Figure 7A: Excess generation (% of VRE before thermal minimum

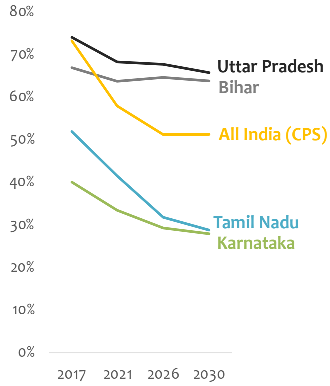

Figure 7B: Load factor of residual demand (%)

Regions and states will ultimately require different mixes of flexibility options to address their specific challenges, tap into flexibility potential of individual states while creating trading opportunities on a regional or pan-India basis. Figure 7shows how different combinations of flexibility drivers such as demand profiles, generation sources and flexibility options would lead to each state being a flexibility importer or exporter.

G. India can pursue ambitious renewable energy targets, but concerted action on data, market design, development, investment, consumer behaviour and infrastructure is essential

Our analysis has shown that flexibility should be addressed urgently to reduce costs and improve the quality of electricity supply, regardless of renewable energy ambitions. However, once flexibility is addressed, the cost of integrating variable renewable energy falls significantly, making clean energy a low-cost option. Developing and integrating each of the categories of flexibility options will require concerted action along the following lines:

1. **Data and information.** Balancing supply and demand continuously is a data intensive exercise. A first step to creating this balance is to build a comprehensive set of data on both the value/benefit of flexibility over time and location, and the potential and cost of each flexibility option.

- On the need for flexibility, data from the dispatch centres and trading markets form the core of required data, but more complete and comparable data will be needed.
- On the supply of flexibility, a central catalogue of the capabilities of all India powerplants – and their potential upgrade – would be an important step, while estimates of daily demand, consumption patterns by end use (for example, agricultural pumping or residential air conditioning), and alternative consumption models are essential before we can develop programmes and incentives to shift these patterns.

2. **Incentives and markets.** While the data identifies the need and potential options, incentives and markets are needed to encourage providers to offer the lowest cost flexibility option, when it is needed, and to work to reduce

the costs of each option. For example, more liquid wholesale electricity markets that create a transparent price signal, more time-varying and dynamic retail prices would encourage demand flexibility, new contract structures with powerplants, demand flexibility aggregators, storage assets that value flexibility characteristics.

3. **Development and cost reduction.** Since flexibility has not been a priority in India, several of the options remain underdeveloped.

- **Batteries and other energy storage options** are developing rapidly internationally, and costs are falling, but local costs, including balance of system, installation, and operation, are an important part of the total costs. India needs to begin deploying batteries soon, so that costs fall enough by the time the technology can be applied at scale and at low cost.
- **Thermal powerplants** can significantly increase the flexibility they offer, in part by reducing the minimum technical level at which they operate and improving their ramp rates. A lower minimum technical, increases the amount each plant can backdown by, thereby increasing the amount of renewable energy that can be absorbed, thus reducing costly renewable energy curtailment. Lowering minimum generation levels requires investment in plant equipment and monitoring and could increase operating costs. India will need to work with existing plant owners to minimize this investment requirement and the associated costs.
- **Demand side options.** Harnessing demand flexibility requires metering, controls, and incentives. It will also require customer awareness and engagement, which is difficult if consumers are uncertain of the benefits and costs of consuming energy while operating more flexibly. Working with consumers to develop these programs and be comfortable with the results will require time.

4. **Investment.** Batteries, plant upgrades, information technology and metering for consumers, may require smaller, individual investments than new, large powerplants, but collectively they will still represent significant investment for India. The investment patterns, time horizons, risks, and the investors themselves, will often be distinct from typical power sector investors. Likewise, investment during the development phase for these options will have different patterns and needs than once the options become mainstream. These differences need to be addressed early in order to accelerate development.

5. **Behavior.** Many of the options presented here are new to Indian electricity consumers or producers. Thus, they may break entrenched practices that have developed over many years. While incentives may provide an economic case, changing behavior – for example to change the hours of agricultural pumping, to accept operating powerplants at lower minimum levels, or changing how a house is cooled – often requires different mechanisms than pure incentives including utility and customer education, development of new business models, creation of new market participants, political will and new policy frameworks.

6. **Policy interventions and frameworks**. A number of the current market structures, incentives and the policy framework that underpin them are structured to support old generation and consumption models. Transitioning into the new behaviours, new market models and incentivizing evolution of operational and financing models will require not just the creation of new pathways (e.g., markets can find the right price for ancillary and balancing services, real-time markets, market aggregators and deployment of control and measurement infrastructure to facilitate demand side flexibility) but also amendment existing contracts and agreements (eg, adjustment of existing thermal generation contracts to compensate for financial and operational cost of flexible operations).

7. **Infrastructure.** Finally, some of the new investment and systems lie with neither producers or consumers, but rather the infrastructure in between. We have already seen how more centralised data might help pursue these ambitions, but there are other common infrastructure needs to accessing greater flexibility:

- **Transmission and distribution** are central elements of delivering and rationalizing flexibility resources. Planning and building these elements will likely increase and need to consider carefully the flexibility needs and resources.
- **Information technology and metering** will drive markets, incentives, payments, and new programme development. Information is a key to balancing this system and creating the infrastructure to gather and use this data is an important step to minimizing costs.

IV. Market Design: Reform, Incentivise, Invest

These interim findings represent the first year of work as part of the program of Energy Transitions Commission India in collaboration with The Energy and Resources Institute and the National Renewable Energy Lab.

Among other requirements like data, infrastructure, technology, and new business models, improving flexibility also requires new market designs for which electricity markets need to consider both the medium-term transition and the longer-term design.

In the medium term, electricity markets need to consider:

- What should we do to develop technologies and flexibility options?
- How can we accelerate decarbonisation of electricity supply?
- How can we encourage investment in an evolving sector, and new technologies and businesses, while maintaining low financing costs?
- How can we overcome entrenched practices to encourage new behaviours and models required for the new energy system?
- How can we facilitate transition to a long-term market design and new technologies and behaviours with a minimum of disruption and cost?

Longer-term design questions for the electricity markets:

- How should supply and flexibility resources be incentivised, dispatched, compensated, etc?
- How should ancillary services procured and compensated?
- How should we balance and compensate for locational differences?
- How to plan, achieve, maintain, and grow a reliable energy system at a low cost?
- What should we do to develop technologies and flexibility options?

Our consultations with stakeholders on the market reform program reveal a number of challenges that exist across the Indian electricity system which increase costs, exacerbate financial risks and threaten to impede the transition to a lower carbon electricity system or at least increase its cost substantially.

Challenges that include the level of institutional readiness, interactions between energy markets and capacity mechanisms, including existing power purchase agreements, efficient use of capacity, support for new and emerging technology and overall reliability of the power system.

These challenges need to be addressed through a coherent set of market models, regulation and incentives tailored to specific issues and opportunities facing India and its states, drawing on both domestic and international experiences

V. Summary

Regardless of how far India moves on its clean energy ambitions, additional flexibility in demand, powerplants and storage will lower the cost and increase the reliability of its electricity supply. Building a programme to improve the capacity and cost competitiveness of storage options in India is an important step that requires development in the near term and deployment programmes in the longer term. Improving demand flexibility through further test programmes, development programmes and market reform and incentives is another step that can provide significant value to India under any circumstances, but they will need to start as soon as is practical to ensure that the flexible capacity is available for when it is needed in the future.

With all three categories developed – demand management, thermal and and storage – flexibility will be the key enabler for reducing system costs, increasing power quality, and transitioning the India power sector into a low cost, low carbon, sustainable system which can support and facilitate increasing renewable energy and lower emissons.

The transition towards well-functioning wholesale and retail power markets can provide a level playing field for efficient and economic technologies such as wind, solar, electric vehicles; demand response, peaking power, flexibility services and its widespread application through rooftop PV, micro-grids and combined heat and power.

CERC and POSOCO are leading a national level dialogue on market reforms, highlighting the need to improve market-based ancillary services, real time markets and more efficient dispatch.

Acknowledging the crucial role of discoms in the implementation of market-based solutions, the CPI EF team is working with the states of Tamil Nadu, Karnataka and Maharashtra with the aim of developing a toolkit which can be implemented by other states in the country as well.

Biographical information

Udetanshu is a Principal with CPI's Energy Finance team in London, focusing on on renewable energy finance, lowering cost of energy transition, energy transition impact on sovereign risk and electricity market design. She is leading Energy Finance team's flagship programs in India, with the Energy Transitions Commission (ETC) India and other private and government stakeholders. Prior to joining CPI, Udetanshu worked as an M&A and financing Investment Banker for HSBC, Credit Suisse and Barclays and then as a funding and strategy consultant, working with Energy Systems Catapult and the UK's Department for Business Energy and Industrial Strategy .

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Mr Khurana's work focuses on developing solutions for a flexible, low carbon energy system and market design. Prior to joining CPI, Saarthak spent four years working in the Indian power utility sector with Tata Power where he was on the Strategy and Corporate Planning team driving the competitor and market intelligence initiatives as well as developing and maintaining the long-term financial plans for the organisation.

In his additional capacity as a Tata Business Excellence Model (TBEM) certified assessor, he has also undertaken Business Excellence assessments for multiple Tata Group companies.