CLIMATE POLICY INITIATIVE

Developing a roadmap to a flexible, low-carbon Indian electricity system

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February 2020

A CPI Energy Finance report: executive summary

Acknowledgements

This paper has been produced by the Energy Finance team at Climate Policy Initiative (CPI EF) as part of the first year of a programme run by the Energy Transitions Commission (ETC) India undertaken in collaboration with The Energy and Resources Institute (TERI) and the National Renewable Energy Lab (NREL).

Insights contained in this paper represent CPI EF's findings based on demand and supply scenarios published last year by TERI Analysing and Projecting Indian Electricity Demand to 2030 and Exploring Electricity Capacity Scenarios to 2030: Scenario Framework.

We are grateful for the support of our sponsors and partners, ETC India, Hewlett Foundation, Children's Investment Fund Foundation, TERI and NREL. We would also like to acknowledge the support from multiple stakeholders we engaged with throughout the development of the analysis and who took part in the meetings and workshops, including the Ministry of Power, Ministry of New and Renewable Energy, Central Electricity Authority, Central Electricity Regulatory Commission, Power System Operation Corporation, NTPC, Tata Power, Siemens and BSES.

The findings in this paper reflect the analysis conducted by CPI Energy Finance. An interim version of this paper was published in February 2019. Special thanks goes to Brendan Pierpont, formerly a principal at CPI Energy Finance.

Descriptors

Keywords	Renewable energy, flexibility, solar, wind, thermal, demand response, energy storage
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About CPI

Climate Policy Initiative works to improve the most important energy and land use policies around the world, with a particular focus on finance. An independent organization supported in part by foundation funding, CPI works in places that provide the most potential for policy impact including Brazil, China, Europe, India, Indonesia, and the United States. Our work helps nations grow while addressing increasingly scarce resources and climate risk. This is a complex challenge in which policy plays a crucial role.

CPI's Energy Finance practice is a multidisciplinary team of economists, analysts and financial and energy industry professionals focused on developing innovative finance and market solutions that accelerate the energy transition.

Executive summary

Decarbonisation of electricity and significant expansion of it as an energy resource are two of the most important tasks in mitigating climate change and meeting international greenhouse gas emission reduction targets[1]. In our analysis for the Energy Transitions Commission[2] in 2017, we demonstrated the feasibility and critical importance of improving electricity system flexibility in order to decarbonise electricity supply systems at a reasonable cost. The need for additional flexibility, the mix of available options, and their relative cost is highly dependent upon regional circumstances including weather, energy resources and demand patterns. Thus, the conclusions of the 2017 report, and the policies and incentives to deliver the options, need refinement at the national and regional level.

In India, increasing flexibility resources from its powerplants, energy storage and demand response has strong potential to help build low-carbon electricity systems. In fact, our analysis suggests that flexibility in India could reduce total system electricity supply costs by up to 5% on average, while improving the quality of supply. Further, if India achieves higher levels of flexibility, it will significantly increase the rate of deployment of renewable energy at little or no extra cost.

In other words, a low-carbon Indian electricity system with higher flexibility levels is significantly less expensive than the existing energy mix with current levels of flexibility.

Additionally, this report finds that flexibility needs will grow much faster than energy demand in India under any probable renewable energy deployment path. A shortage of flexibility could soon impede energy system growth and put at risk recent progress India has made to reduce involuntary load shedding and improve power quality. However, the report also finds that India has many potential flexibility options that could meet these growing needs, but electricity markets, infrastructure, technology and business models need to adapt and develop to access these options effectively. This development needs to start now to ensure that the options are available as the need arises.

Finding 1: In India, flexibility needs are growing much faster than energy demand

Electricity system flexibility is not a single resource, but rather, a collection of actions across different time frames. In our work, we define four main categories of flexibility, with locational flexibility as a fifth category:

- **Short-term reserves and load following**. Electricity systems need access to standby

What is electricity system flexibility and why is it important?

Electricity supply and demand must be matched instantaneously at each moment of each hour, every day of the year. Failure to do so causes more than just flickering lights. Spikes in electricity supply voltage and frequency damage equipment, close factories, and can cause electricity transmission systems to become unstable and fail, leading to blackouts and damage to infrastructure, and industrial and consumer equipment.

Historically, most electricity systems have been managed by increasing or decreasing output from hydro or thermal generators in response to changing demand. When a greater share of electricity demand was from continuous loads such as industry, this process was relatively easy. As the share of demand from residential and commercial consumers has grown, overall demand has become more variable. As a result, thermal powerplants have had to work harder, ramping output up and down, to match demand. Meanwhile, many of the low carbon energy supply options, including wind, solar, run-of-river hydro, and even nuclear, create more system challenges as their output varies with wind, rain or sunshine. In India, thermal plants have already reached limits on how fast they can ramp up or down, or how much electricity they can shift from one part of the day to another within current contractual agreements and operational practices, leading system operators to curtail excess supply.

Yet with the right incentives, power plants can make investments and change operating practices to become more flexible, demand can begin to respond to energy supply availability, and storage can be built to optimise this matching process.

1 Better Energy, Greater Prosperity, Energy Transitions Commission (2017) http://www.energy-transitions.org/better-energy-greater-prosperity

2 Flexibility: the path to low-carbon, low-cost electricity grids, Climate Policy Initiative Energy Finance (2017) https://climatepolicyinitiative.org/publication/flexibility-path-low-carbon-low-cost-electricity-grids

capacity that is ready to increase or come on-line instantaneously if there is a sudden powerplant or transmission outage, or demand surge. The increase in variable renewable energy has the least impact on this type of reserve, since needs are driven by the largest potential failures on a system, which are often large thermal powerplants or transmission lines or demand events.

- **Ramping** is the speed at which supply resources can increase or decrease to meet changes in demand from one minute to the next. Declining solar energy production in the evening, the very time that Indian households turn on the lights, cooking appliances and air conditioners, leads to significant increases in ramping needs at the evening peak.
- **Daily balancing** is the requirement to shift energy production (or demand) from one part of the day to another. Increased solar production during the day combined with increased air conditioning demand in the evening increases the need to shift energy from the day to the evening.
- **Seasonal balancing** is the requirement to shift energy (or demand) from one time of the year to another. In many countries seasonal balancing is related to winter heating demand or summer air conditioning demand or the seasonality of solar production. In India, the variation in solar production and even air conditioning (or heating demand) is relatively smaller than in many other countries. However, the variability of both demand and production from wind generation during the monsoon season creates a large monsoon driven seasonality in many regions of India.

Figure ES-1: Growth in flexibility needs

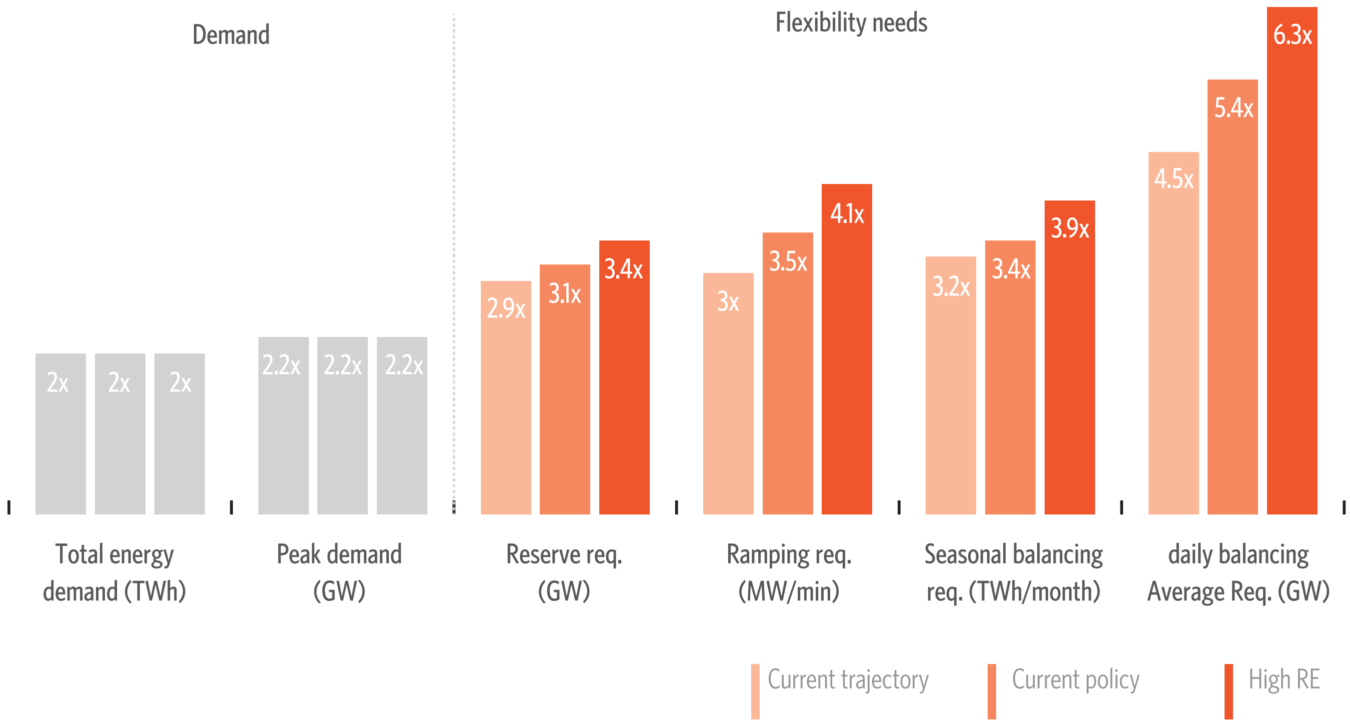
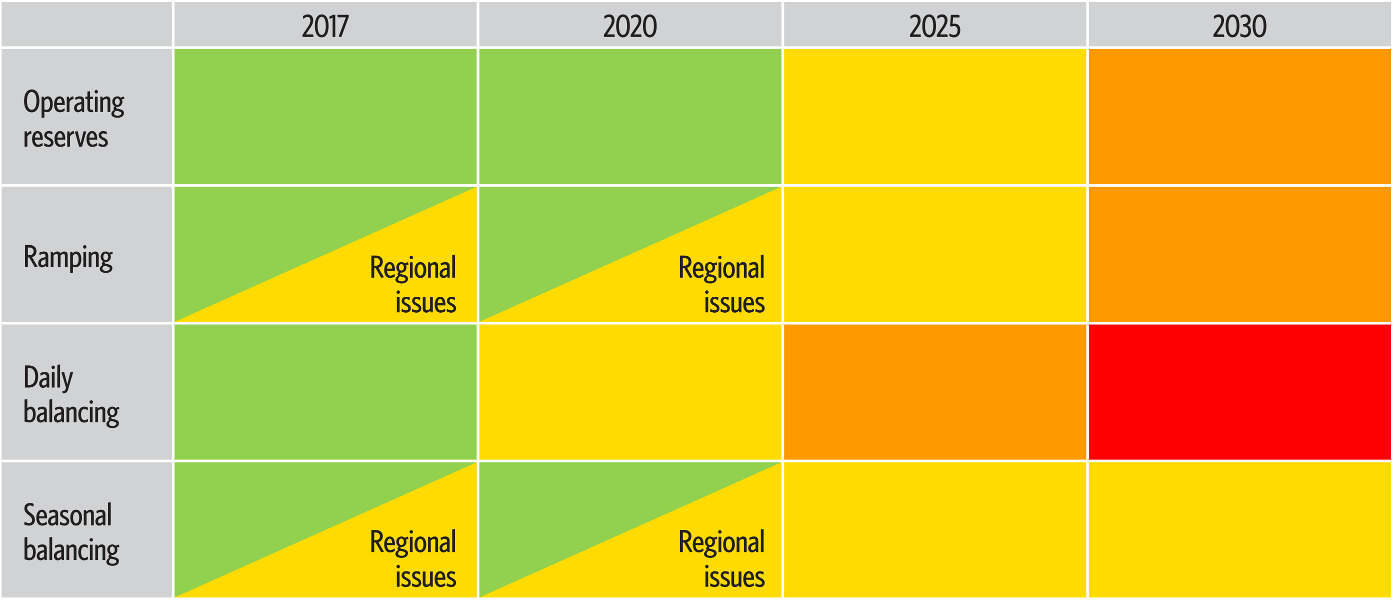


Figure ES-1 shows how each of these four categories of flexibility needs will increase in India under different renewable energy scenarios between now and 2030. The **current trajectory scenario** maintains current renewable energy growth rates, the **current policy scenario** assumes that India meets current policy targets, while the **high renewable energy scenario** assumes that India accelerates renewable energy deployment in line with increased climate mitigation objectives. In the latter scenario, many of the flexibility needs grow two to three times faster than electricity demand.

Figure ES-2: Without additional resources, flexibility will become a serious constraint in the near future under a high renewable scenario



Finding 2: Without additional resources, flexibility will become a serious constraint in the near future

Building on demand growth and load shape forecasts, and matching against existing flexibility resources, our modelling indicates, as in Figure ES-2 above, that India needs more of all types of flexibility by 2025, that under the high renewable energy scenario, India needs more of all types of flexibility by 2025, with daily balancing becoming critical by 2030. Today, India is beginning to experience challenges at a regional level, including fast increasing ramping needs in states like Karnataka due to high solar energy penetration, and significant seasonal flexibility needs in Tamil Nadu due to monsoons and large wind energy capacity.

Finding 3: India has many potential flexibility options that can be developed in time to meet these future needs

Our analysis addresses three main categories of flexibility option:

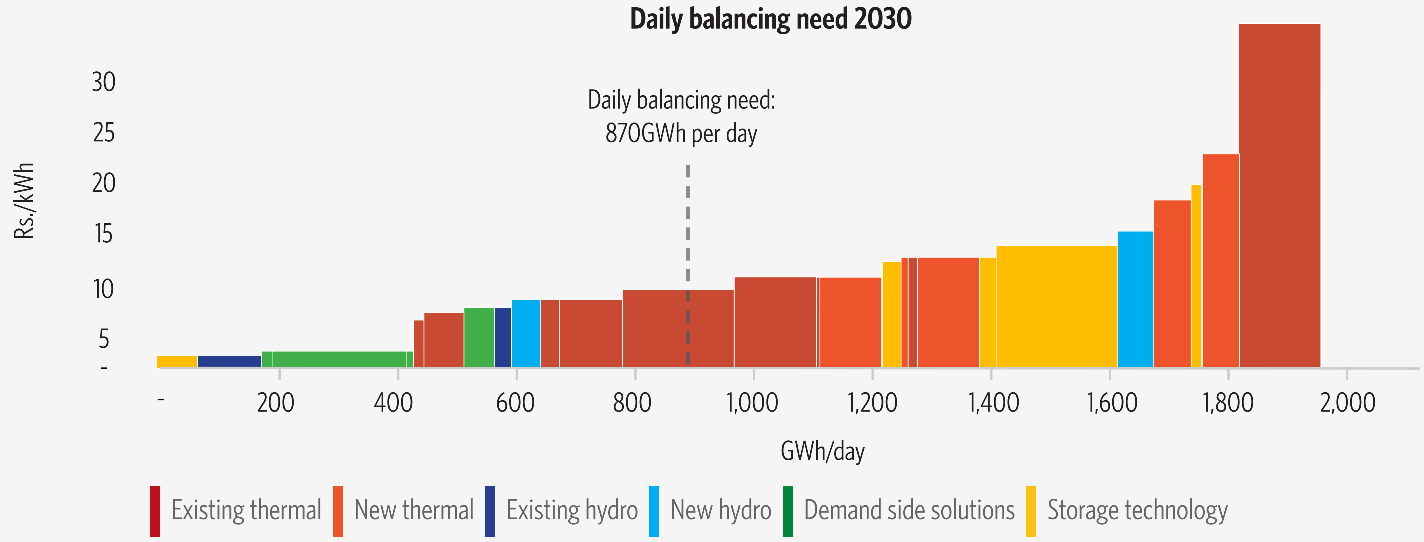
- **Demand side flexibility:** Improving the ability of consumers to modify their demand in ways that could help the system match electricity supply to demand;
- **Powerplant flexibility:** Technical, economic, and contractual solutions to improve the responsiveness of powerplants to variations in demand and renewable energy output;
- **Storage:** Including battery and other storage options to shift demand or supply in ways that could help match supply and demand.

For each flexibility option we have estimated the national potential and per unit (GWh/day, etc) cost to create a supply curve. We have estimated how these costs could evolve between now and 2030. Figure ES-3 on the following page shows how the mix of flexibility options could compete with each other given potential cost reduction through to 2030 for one type of daily balancing need (6 hours a day). Lowest cost options are on the left, with increasingly expensive options as we move to the right. Note that demand for daily shifting in a high renewable energy case is about 870GWh/day. With nearly 2,000GWh/day available, this need, like all others, is potentially well supplied even with the accelerated deployment of wind and solar.

Finding 4: Integration of higher levels of flexibility will significantly reduce total costs, particularly if India can develop a portfolio of demand, powerplant and storage options

Understanding how flexibility will affect the cost and reliability of the Indian electricity system requires modelling of the range of portfolio options available to simultaneously meet all electricity demand and flexibility needs, keeping the system in balance. We modelled different sets of demand, storage and powerplant flexibility options against current and

Figure ES-3: Supply and demand for daily balancing - high RE scenario 2030



future load shapes. Figure ES-4 shows how the mix of generation and flexibility resources would fit together in a single week in 2030. The left chart includes demand and storage flexibility options, while the right chart includes only powerplant based flexibility options. The black line represents the pre-flexibility load that needs to be met across the week. Note how in the right hand (powerplant only graph) coal fired powerplants (in black and grey shades) need to vary their production across the day and in some cases will need to be upgraded to turn on and off each day. Note also that there is a considerable amount of solar energy above the black line that will be curtailed. That is wasted. On the left hand side powerplants operate more continuously and with less variation, while most of the excess energy from solar production is either stored or used by demand shifted from other times of the day.

Figure ES-4: Demand flexibility and storage reduce curtailment and allow thermal plant to operate more efficiently

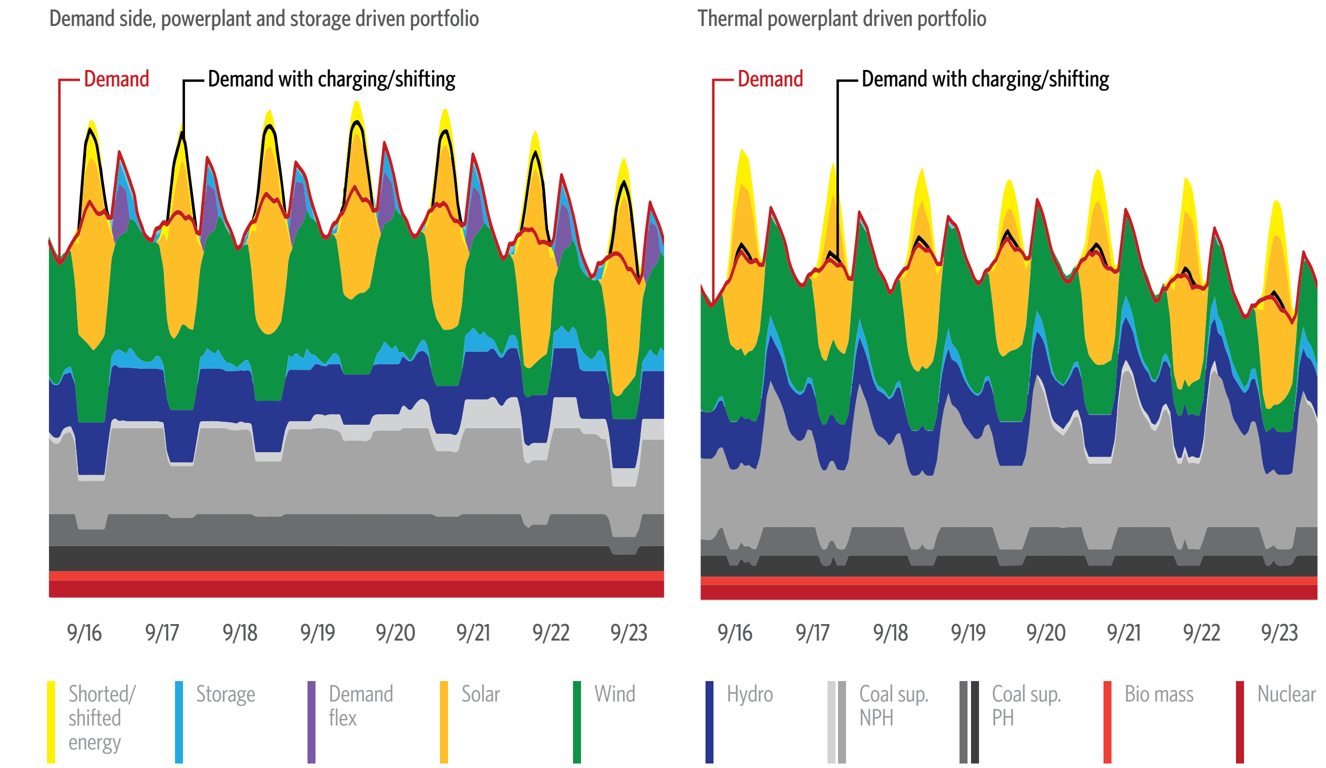
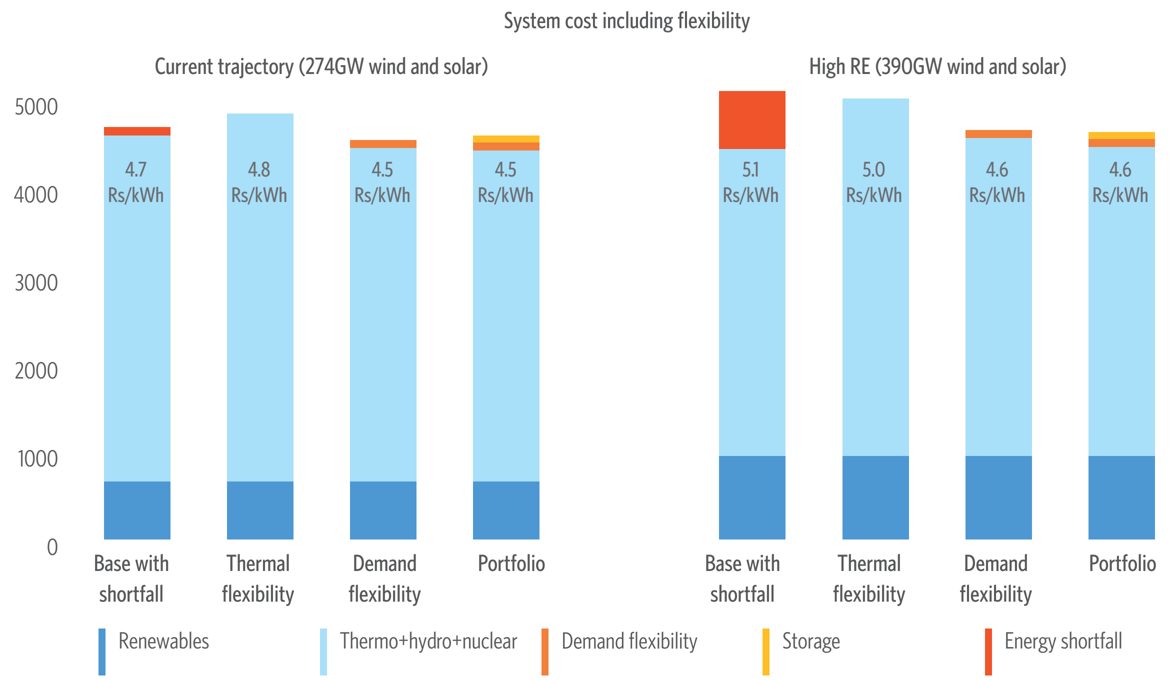


Figure ES-5: Impact of flexibility on total Indian electricity system costs



Additional flexibility from different resources will deliver an efficient and reliable electricity system, but the question is whether these improvements justify the investment and operating costs of the flexibility options. Our analysis, summarised in Figure ES-5, shows unequivocally that it does.

Figure ES-5 compares the average system price for all electricity supply in India including the total costs of new flexibility options under the current trajectory and high renewable energy scenarios. Figure ES-5 compares four sets of flexibility portfolios, existing flexibility, improvements in flexibility from powerplants only, increase in demand flexibility only, and a portfolio of flexibility options including demand flexibility, powerplant flexibility and storage that optimizes total system cost.

In the base case, the system will continue to have significant energy shortfalls at different times of the year. We have included the cost of meeting this shortfall with generator backups as a proxy for the economic impact of the shortages. Note how increasing powerplant flexibility only will eliminate energy shortfalls, but will increase overall system cost. Using the full portfolio of options is 5% cheaper than the base case at current renewable energy deployment rates and 8% cheaper in the high renewable energy case. In summary we find:

1. Balanced and demand flexibility portfolios significantly reduce carbon, costs and curtailment, even at low RE ambitions.
2. Combinations of flexibility options can have significant impact on system efficiency, for example deployment of demand flexibility and storage enable thermal powerplants to operate more steadily and efficiently in a balanced flexible portfolio.
3. Costs of integrating renewables can be kept low by optimising the utilisation of flexibility resources to meet particular flexibility needs, for example, energy storage from batteries is most suited to daily balancing, rather than meeting seasonal needs.
4. Our analysis shows that the mixed portfolio has 5% to 8% lower system costs, 8% to 12% lower carbon emissions and requires between 82% and 97% less curtailment.

Figure ES-6: Curtailment is dramatically reduced as are costs and carbon under a balanced portfolio

Portfolio performance (2030) - current trajectory

Scenario	Excess energy	Total cost	Carbon emissions
Power-plant driven	10%	4.8 (Rs/kWh)	4.8 (t/MWh)
Demand flex driven	-83%	-6%	-6%
Storage driven	-95%	-4%	-6%
Balanced portfolio	-97%	-5%	-8%

Portfolio performance (2030) - high RE scenario

Scenario	Excess energy	Total cost	Carbon emissions
Power-plant driven	13.8%	5.0 (Rs/kWh)	0.5 (t/MWh)
Demand flex driven	-63%	-7%	-9%
Storage driven	-80%	-5%	-10%
Balanced portfolio	-82%	-8%	-12%

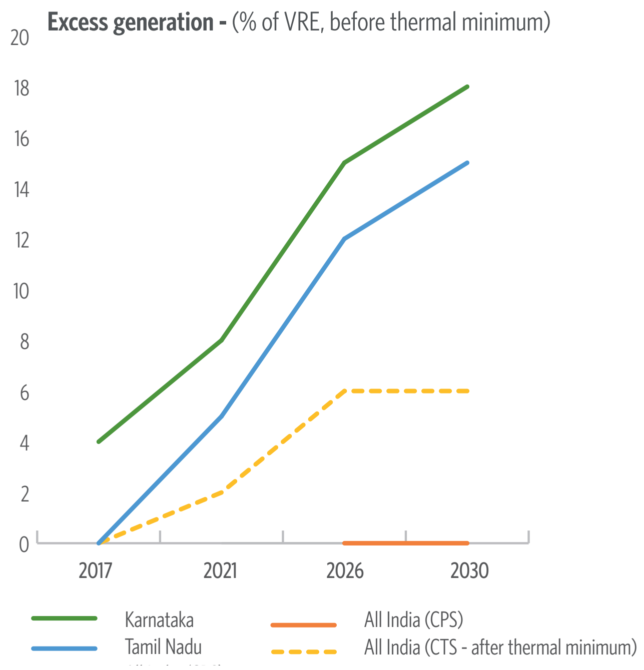
Figure ES-6 compares the average system price, the carbon impact and curtailment across four sets of flexibility options, starting with maximising flexibility from power plants, and comparing that to increases in demand flexibility only, and a balanced portfolio of flexibility options including demand flexibility, powerplant flexibility and storage that optimises total system cost.

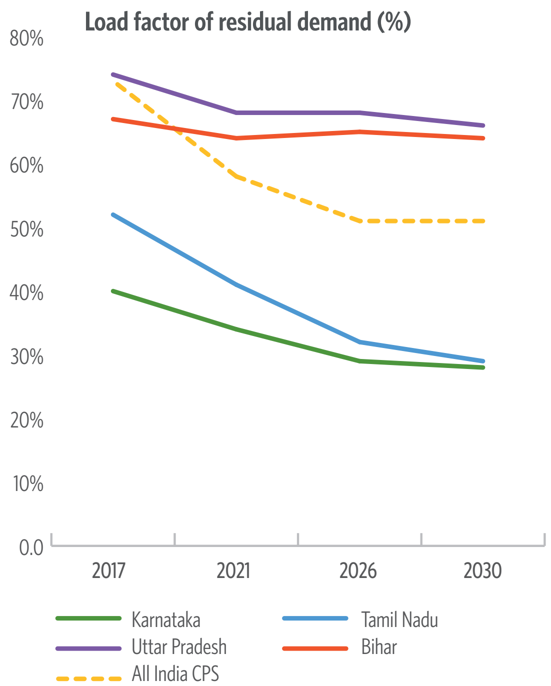
Finding 5: Development needs for flexibility will vary significantly by region

Just as there are variations internationally, there are significant variations within India. States such as Karnataka and Tamil Nadu that have experienced significant economic growth as well as renewable energy deployment have seen greater increases in flexibility needs.

Figure ES-7 shows how the needs in those two states will grow in the high renewable energy scenario by 2030 versus the India average and the impact on two states with lower deployment (Bihar and Uttar Pradesh). Without interstate transfers and flexibility improvements, by 2030 Karnataka and Tamil Nadu could see up to 15%-20% of their renewable energy generation curtailed, versus 6% as an average across India. One measure of flexibility needs is the load factor required of thermal generation in the state. In Tamil Nadu and Karnataka, without interstate transfers, thermal generation load factors could fall to 30%. In states like Uttar Pradesh or Bihar capacity factors fall only slightly to around 70% over the same period.

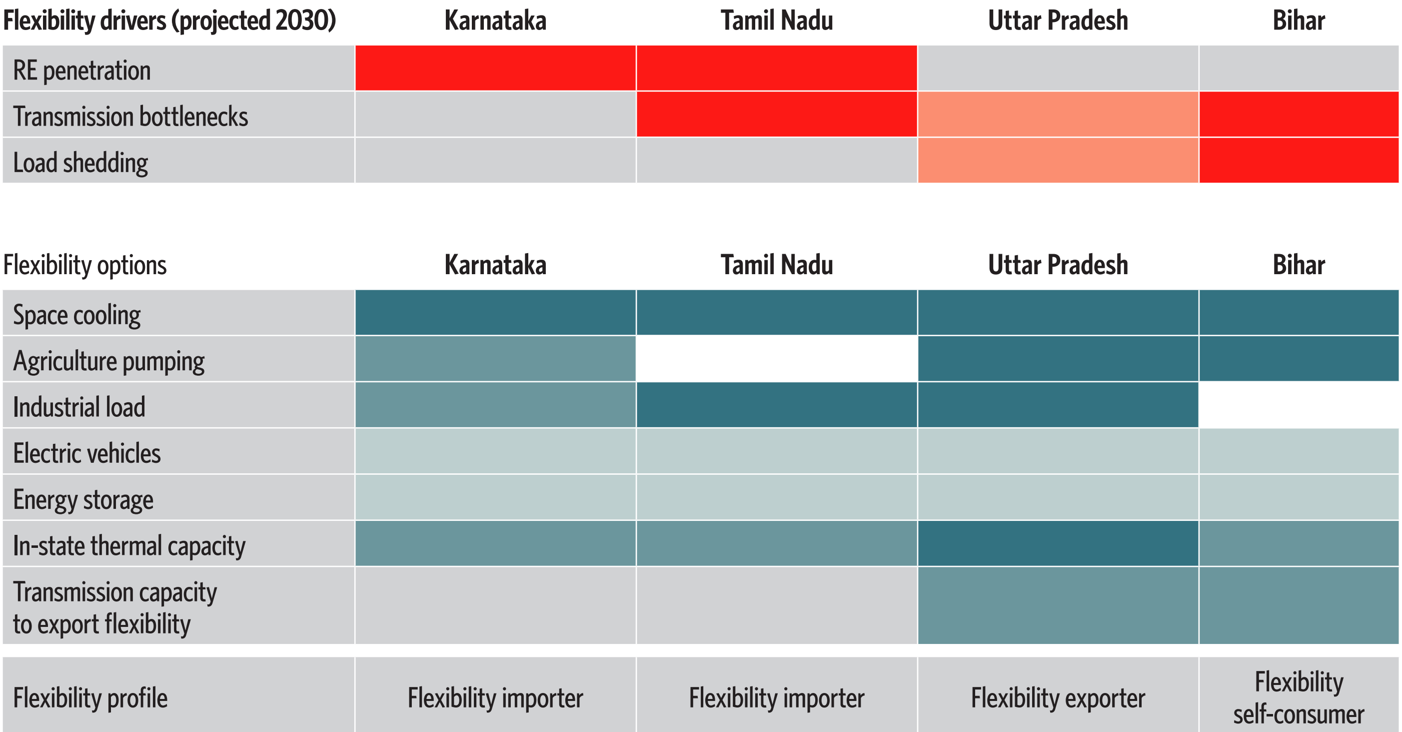
Figure ES-7: Forecast growth of renewable electricity generation in the state vs India overall





Renewable energy penetration is only one of many factors that will affect flexibility needs and supply going forward. Figure ES-8 summarises some of the key factors affecting state supply and demand of flexibility and shows that if India can improve national markets for flexibility supply, states like Uttar Pradesh can benefit from exporting its flexibility capacity to states like Karnataka and Tamil Nadu. States like Bihar, meanwhile, should be able to improve its flexibility to reduce load shedding and improve power quality.

Figure ES-8: Key factors affecting state flexibility supply and demand



Finding 6: India will need to adjust elements of its electricity system, including data, technology, infrastructure, business models, incentives and market design, if it is to achieve its flexibility goals

Finally, developing demand flexibility, storage, increasing the flexibility of thermal and hydro powerplants, planning the integration of transmission to enable and enhance flexibility all require different types of policies and markets that will help integrate these options once they are developed. India needs to develop:

- **Data,** for example, to understand which consumers could change their electricity consumption patterns and at what costs;
- **Technology,** for example, to reduce the costs of storage and to create different types of storage systems that meet the needs of the various segments of the Indian electricity market (industrial, renewable energy plus storage, transport, household and commercial energy back up/back up generator replacement, etc);
- **Infrastructure,** such as transmission, to deliver flexibility, or the IT and metering systems to schedule and integrate flexibility;
- **Awareness,** from consumers, potential storage investors and powerplant operators as to the potential and value of flexibility from their assets;
- **Business models,** that enable investors, consumers and others to monetise and benefit from providing their flexibility;
- **Incentives,** that align flexibility providers with overall system needs.

Once all of these are in place and the flexibility options are deployed at reasonable costs, the technical market design can integrate the flexibility. Figure ES-9 summarises some of the critical needs that India needs to address for each of the flexibility options and integration of those options. CPI is working with states and national regulators to identify market design and policy solutions to address each of these issues.

Figure ES-9: Factors that increase flexibility resources must be integrated by market design

	Data Develop, improve, disseminate	**Technology** Develop, deploy, cost reduction	**Infrastructure** Plan, finance, build	**Awareness** Build and drive behaviour	**Business models** Facilitate development	**Incentives** Provide and harmonise	**Market design** Improve and integrate
Demand flexibility Develop, test, and roll out options	• Demand statistics • Potential • Cost	• IT and control systems	• IT and control systems	• Opportunities • Consumers	• Models for aggregators	• Investment • Dispatch	Integrate all options cost effectively
Storage Develop and install	• Potential • Cost	• Cost reduction • Local application • Indian manufacture	• Deploy, integrate, finance	• Opportunities	• Aggregators • Producers • Suppliers	• Capital investment • Dispatch	
Powerplants Encourage operation and regulatory changes and investment	• Integrated assessment of system plant • Value • Potential	• Test and deploy upgrades	• Test and deploy	• Overcoming entrenched practices • Operating and regulatory	• Plant owners • Upgrades	• Capital investment • Dispatch	
Transmission Continue expanding with flexibility needs under consideration	• Regional data • Cost compare • Flexibility in planning	• Use state of art as deployed in India	• Finance • Integrate	• Tradeoffs with flexibility	• Local, regional and national	• Regulation trading markets	
Integrate Each of the options to minimize cost	• Central clearinghouse for planning	• IT for systems integration and markets	• Financial capacity and planning		• Build aggregators • Help players work together		

For policymakers, this report should provide the reassurance that both renewable ambitions are realistic and the costs of renewables and their integration do not present a barrier to decarbonise and modernise India's power system. In fact, a lack of ambition would be more expensive for India as the energy transition represents an opportunity to create a more efficient system that is not only low-carbon, but also lower cost. The report should also serve to highlight the importance of thinking broadly about the range of issues, activities, policies, market design and investment issues India needs to address to continue to reduce the cost of electricity in India, while improving its reliability and quality and reducing its carbon footprint.

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