CLIMATE POLICY INITIATIVE

Electricity market reform – Karnataka case study

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Descriptors

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Table of contents

Executive summary

Karnataka is well placed to meet its energy needs over the next decade thanks to its rapid deployment of renewables as part of India's ambitious decarbonisation programme, which aims to reduce emissions while meeting energy demand and supporting economic growth.

At the end of 2019, Karnataka's solar capacity stood at 7.3GW, the highest of any state in India and almost 22% of the total deployed in the country. Overall, the state accounts for 22% (15GW) of India's total installed capacity[1]. These achievements have helped put India on track to meet its carbon reduction targets agreed under the Paris accord in 2015[2].

However, capacity additions alone will not be sufficient to develop an economically efficient power system that reduces carbon emissions at low costs. Like the rest of the country and its neighbouring state, Tamil Nadu, Karnataka is at a critical inflection point with respect to the electricity market design and the structure of the electricity industry.

Previous analysis for the Energy Transitions Commission showed that for generic electricity systems[3], as well as for India when taken as a whole[4], the total cost of a low carbon electricity system would be lower than the cost of the current energy mix, including all system and integration costs. However, this analysis also suggested that these benefits could only be achieved if market mechanisms and other measures could increase the flexibility of both supply and demand of electricity to adapt to changing demand patterns and the variability of renewable energy supply.

This analysis also indicated the importance of local and regional differences in the demand and supply for flexibility and the need to evaluate options and plans at state level to understand fully the costs, potential, and issues that may arise. This case study is one of a series of regional and national studies in India that addresses key elements of electricity market reforms and technology development that are central to the ability of Karnataka, and India as a whole, in meeting this challenge.

In this case study, we have:

- Assessed the cost, development, capital requirements and timing of potential flexibility options – including flexibility from demand, energy storage, and powerplant flexibility – through to 2030 across three main flexibility scenarios, Current Trajectory (CTS), Current Policy (CPS) and the High Renewables Scenario (HRE)
- Assessed the higher renewables scenarios (CPS, HRE) without any powerplant pipeline – ie, no additions of coal, gas or hydro powerplants beyond the existing operational capacity.
- Modelled the dispatch of Karnataka's electricity system in 2030 using different generation capacity additions and different mixes of flexibility options to determine the impact of these mixes on cost, carbon emissions, excess energy that is wasted and potential load shedding
- Identified development needs, barriers and market mechanisms that could help Karnataka achieve the system benefits identified.

Although our analysis has found similarities with the India-wide cost and carbon benefits of flexibility, the state's flexibility needs are accelerating faster than the rest of the country due to Karnataka's peculiarities around fuel procurement for its coal powerplants, along with its

[1] KPCL Annual report, 2019, SRPC; Annual report, 2019

[2] India has three main NDCs: 40% of electricity to come from non-fossil fuel sources by 2030; to reduce the emissions intensity of India's gross domestic product (GDP) by 33-35% compared to 2005 levels by 2030; and to create carbon sinks of about 2.5-3 billion tonnes.

[3] Better Energy, Greater Prosperity, Energy Transitions Commission (2017) https://www.energy-transitions.org/publications/better-energy-greater-prosperity/

[4] ETC India report https://www.climatepolicyinitiative.org/wp-content/uploads/2020/08/CPI-India-flexibility-25-August-2020-full-report-1.pdf

leadership role if solar capacity deployment. In the absence of greater flexibility through planning, ramping and daily shifting needs could start creating system constraints in the next few years. By 2030, renewable energy generators could see curtailment of 15-20% of renewable capacity in Karnataka, almost triple that of India's average. Thermal generation in Karnataka is already seeing strong variations, with monthly load factors below 40% for many state units, a situation which is likely to deteriorate further adding stress to both coal powerplants as well as the overall electricity system without the development and integration of flexibility resources, including options for powerplants to provide flexibility services and recover relevant costs.

Four main findings have emerged from this work:

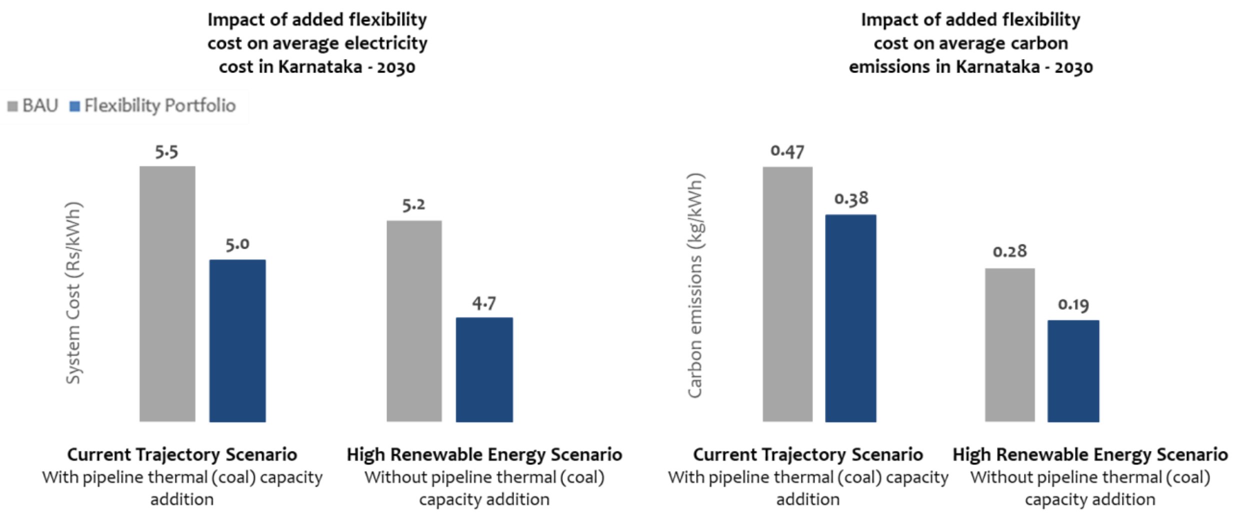
1. **Flexible energy markets reduce costs, the need for curtailment and emissions**. If Karnataka were to have no access to interstate flexibility or power exchanges, increasing flexibility to its electricity system through markets and flexibility resource development and investment could reduce electricity costs by up to 10%, the need for curtailment (by reducing excess energy) by up to 85% and emissions by up to 35%
2. **A portfolio of flexibility options provides the most promise**. Flexibility from demand is often the lowest cost of the three types of flexibility options, but a portfolio that also includes storage and additional powerplant flexibility provides greater certainty and additional carbon benefits.
3. **Interstate markets and transmission can provide additional value**. Integration into an India-wide market could reduce system costs in Karnataka by a further 7%.
4. **Developing appropriate market mechanisms to encourage the development of flexibility options is critical**.

Finding 1: Flexible energy markets reduce costs in Karnataka

We find that the development of flexibility from demand, energy storage, and flexible generation from powerplants can reduce system costs even without access to interstate or regional power markets.

In order to focus on the value, supply, and demand for flexibility in Karnataka, we began our analysis by modelling the extreme case where Karnataka stands on its own, with limited electricity transfers with neighbouring states and the rest of India. While this model forms one extreme, the India model, which effectively assumes there are no transmission or market limitations between states, forms the other. The likely outcome would be somewhere in between.

Figure ES1 The impact of adding flexibility markets and options on electricity costs and carbon emissions in Karnataka - 2030



Source: CPI analysis

For an isolated Karnataka system, we found that enhanced flexibility can reduce average electricity costs by up to 10% and carbon emissions by up to 35%, as in figure ES1 on the previous page.

Our analysis was based on estimates for the cost and potential of flexibility in Karnataka, including that provided through greater participation of consumers in electricity markets, with battery storage, and enhanced flexibility in the operation of powerplants.

We modelled the system with three different levels of renewable energy build out, one based on the current trajectory, a second based on current policy, and a third, higher renewable energy scenario. The current policy and higher renewable energy scenarios, when combined with higher flexibility, made the addition of new thermal capacity redundant, without sacrificing resource adequacy and reliability. Thus, even with the retirement of some of the oldest units at the Raichur Thermal Power Stations (RTPS), Karnataka can eliminate the 1.6GW pipeline for the expansion of the Udupi Thermal Power Plant.

Our analysis shows that, as for India as a whole, adding flexible resources reduces costs and carbon emissions at any level of additional renewable energy supply, and thus should be pursued under any scenario. Furthermore, the analysis shows that once greater flexibility is achieved, even higher levels of renewable energy supply, and reduced carbon emissions, can be achieved without increasing average electricity costs.

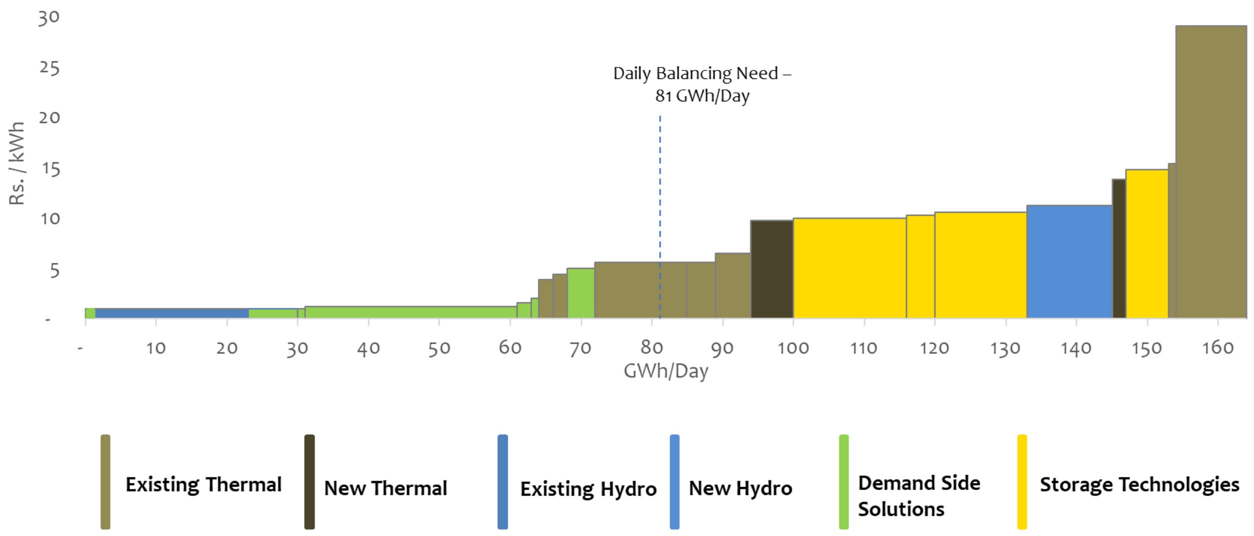
Finding 2: A portfolio of flexibility options provides the most promise.

We studied the potential and cost of three main sets of flexibility options:

- **Flexibility from demand.** Increasing the ability of agriculture, industrial, commercial and residential electricity consumers to adjust the timing of their electricity usage in response to price signals, to coincide with energy supply and thus reduce system costs.
- **Energy storage.** Using battery storage to shift energy supply from times of excess energy production to times of excess energy demand and meeting the ramping up of evening demand peak just as solar generation starts ramping down.
- **Powerplant flexibility.** Increasing the ability of thermal and hydroelectric powerplants to vary output in response to electricity supply and demand, and prices.

Our analysis covers many different needs for flexibility to balance an electricity system, from short term reserves where near-instantaneous response is required to manage surges or dips in electricity demand or supply, to ramping – the speed at which supply can increase to meet rising demand, to the ability to shift demand from one season to another – for instance the monsoon with high wind and hydro output to a season with higher demand. Figure ES2 on the next page is a supply curve for daily balancing, that is, it ranks the lowest cost options to shift surplus energy production over the course of one day by cost and output. The options to the left of the chart are the lowest cost, with costs rising as more flexibility supply is needed.

Figure ES2 Daily balancing supply curve for Karnataka 2030



Source: CPI analysis

Figure ES2 shows how the costs of flexibility from demand, energy storage, thermal and hydro powerplants would compare in 2030, including very significant expected reductions in energy storage costs. Crucially, for an average day, all daily shifting could be met at the lowest cost with a combination of the existing supply from powerplants, from new demand side measures, and from storage flexibility from the two-way charging of electric vehicles (EVs). Other flexibility needs have different patterns, with different mixes of demand, powerplants and storage providing the lowest cost set of options.

Across all flexibility resources and flexibility needs, we found that flexibility from demand is generally the least expensive resource, even factoring in additional costs for technology upgrades, systems and processes. For Karnataka, our analysis focused on the potential for flexibility from four key demand sources:

- **Agriculture pumping** represents over one-third of the demand in Karnataka and flexible operation of pumping provides a low-cost opportunity for flexibility, but one that requires completion of the current programme of separation of agricultural feeders or their solarization, new metering and pricing schemes and control systems.
- **EV charging** presents one of the cheapest forms of flexibility across many balancing needs, but access to this flexibility will require careful development of business models, charging infrastructure and incentives with real time pricing.
- **Space cooling** is a third option with a high potential for meeting reserves and ramping needs, given the rapid growth forecast for cooling demand, but one that requires especially designed incentives and metering to change behaviour
- **Industry** consumes a little under 20% of Karnataka's electricity supply. Options to shift demand and provide flexibility are very dependent on industry segment and facility. We estimate that industrial flexibility potential is only a small proportion of the potential available from agriculture or EV charging for ramping reserves or daily flexibility. However, industrial demand provides an attractive opportunity for seasonal load shifting. By improving incentives to manage maintenance periods or production schedules, industrial load shifting can provide competitive paths to seasonal flexibility.

Our experience is that the response of consumers is unpredictable, so we have taken conservative estimates of the potential from demand flexibility. Thus, we believe that our estimate for potential is likely to be low. Nevertheless, a specifically designed programme targeted at consumer behaviour change and that starts early could help achieve high levels of demand flexibility.

Energy storage is the easiest of the three sets of options to visualize. Plug a battery into a renewable heavy electricity system and, with the right price signals, the battery charges when there is excess energy and discharges when the system needs more energy. At the right price, it is very well suited to meet Karnataka's growing flexibility needs that will be dominated by ramping and daily shifting requirements. Battery storage is the least dependent on local conditions out of all three options. While flexibility from demand depends on the mix of consumers, their equipment and even the weather, powerplant flexibility depends on the powerplants already in place. National factors such as equipment cost, and design dominate storage flexibility options. Thus, many of our findings from the national analysis hold true. Namely, that despite a 85% decrease in cost and improved performance since 2010, and an anticipated further 65% decline in cost by 2030, batteries remain a high capital cost. However, storage economics improve when batteries can be used across several flexibility needs, and when battery applications are tailored to meet specific needs, such as wholesale market flexibility, distribution investment deferral, industrial/commercial backup and power quality, or EV charging.

The major local determinant of storage potential – beyond the use in different consumer modes – is the residual load to be met, and the relative value and competition from dispatchable powerplants and flexibility from demand. Energy storage also has a significant advantage that unlike powerplants or demand, batteries do not need to overcome entrenched practices to make storage useful.

Increased powerplant flexibility. Hydro and coal powerplants already provide the bulk of Karnataka's system flexibility. Unlike its neighbouring state of Tamil Nadu, all of Karnataka's plentiful hydro generation capacity (3.8GW) is available for flexibility. Its state-based coal-fired plants already see monthly PLFs dipping below 40%, driven in equal parts by fuel costs and availability challenges. With the right incentives, contract modifications, market signals, and in some cases investment, there is potential to create and enhance sustainable flexible capacity. For example, lowering the mandated technical minimum from 70% to national standards of 55% could unlock 15% additional daily shifting capacity at little cost except the slightly lower efficiency of operating at a lower output. By 2030, we estimate that powerplants can provide up to 6GW of flexible capacity to the system; 1.6GW of which would require plant upgrades and changes in the cost recovery mechanisms; 840MW of coal capacity would need to be retrofitted for maximum flexibility, ie a technical minimum of 40%. Further flexibility could be added by enabling two-shifting, the shutdown of powerplants during the renewable generation hours, which requires study and investment. This potential is not included in our analysis.

The flexibility potential of older coal powerplants is in some cases limited by design and operating practices as well as contractual constraints. For our analysis, we assume that the oldest state plants only reduce their flexibility floor to 55%, while all other coal plants – state-owned as well as contracted from the center and IPPs adjust to run at a technical minimum of 40%. Overall, we believe, coal powerplants have the potential to make significant contributions to flexible capacity in the immediate term and as Karnataka builds out its renewable infrastructure.

Increasing flexibility from the thermal fleet requires operational changes, retrofit and modernization, the cost of which we include in our development of new flexibility options. Short-term incentives are unlikely to be enough to encourage major retrofits or operating changes. Rather, we believe that long-term contracts for additional capacity and contractual changes will be needed to encourage significant increases in powerplant flexibility.

Building a portfolio of flexibility options. Flexibility from demand, energy storage and powerplants each have advantages and disadvantages in terms of cost, potential, certainty, and speed of development. Developing a portfolio of options thus enables mid-course corrections to ensure that flexibility continues to develop as needed. Proper market signals – for development, investment, and dispatch of the options once available – are essential in encouraging the development of more options and for the dispatch of options once developed.

To understand how each of these options would work together in optimized dispatch, with efficient market incentives and pricing, we ran a model of the system with different portfolios of flexibility options under a range of generation mixes. Figure ES3 shows the results of this modelling and the impact of flexibility portfolios that rely predominantly on enhanced powerplant flexibility, storage, demand flexibility, or a combination of all three to meet flexibility needs. These models assess the impact on excess energy, average system electricity cost and carbon dioxide emissions.

Figure ES3 Portfolio approach to flexibility delivers the highest optimisation on curtailment reduction, CO2 emissions reductions and lower system costs

Current Trajectory Scenario

	Excess	Cost	CO2
Base	13.25%	5.52	0.469
Fossil	-17.8%	-1.8%	-2.1%
Storage	-78.3%	-2.8%	-11.1%
DR	-81.1%	-7.3%	-13.6%
Portfolio	-85.5%	-8.8%	-19.0%

High RE Scenario No coal pipeline

	Excess	Cost	CO2
Base	28.17%	5.24	0.282
Fossil	-3.9%	-3.5%	-2.8%
Storage	-31.5%	-3.0%	-18.8%
DR	-45.4%	-9.5%	-32.6%
Portfolio	-50.4%	-9.6%	-34.0%

Source: CPI analysis

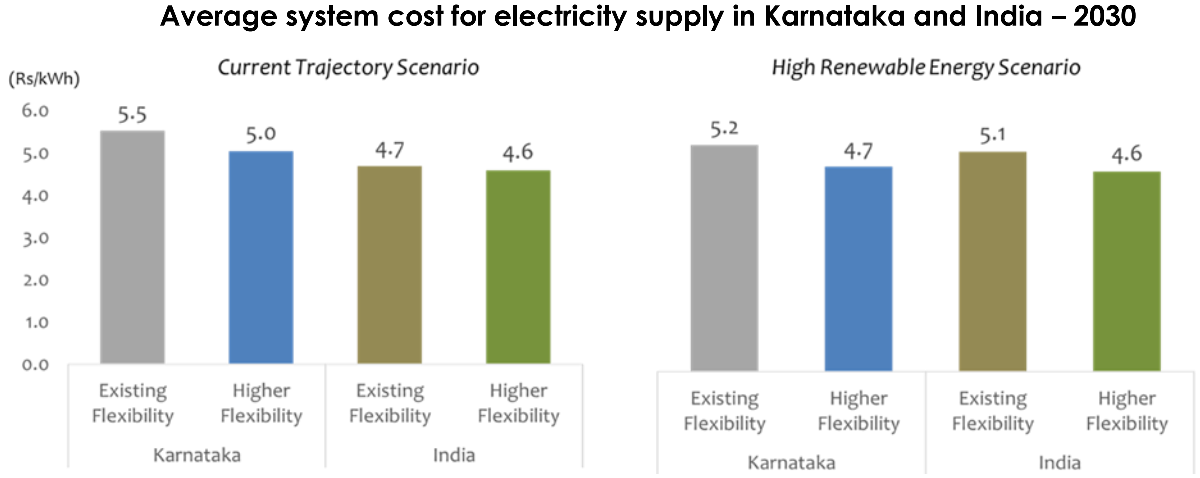
The results indicate that using a portfolio of options leads to the lowest cost solution, maximum reduction in excess energy and carbon emissions. Furthermore, the portfolio will provide greater security in development, as failures to meet flexibility from demand targets could be offset by acceleration of powerplant flexibility or storage development.

Finding 3: Interstate markets and transmission can provide additional value.

While our analysis modelled one extreme of an isolated Karnataka system, the other extreme is a completely integrated system with no transmission constraints and access to flexibility markets – for both demand and supply – across India. The comparison suggests that strong transmission links and broader markets could provide further benefits.

In particular, our analysis shows that costs for Karnataka could be a further 7% lower with integration into an India wide market. Karnataka will need strong transmission linkages and participation in regional and trading and exchanges to fully harness the benefit of its high shares of renewables in its energy mix. Karnataka’s ability to transact flexibility would be value accretive as well as significantly reduce the need for curtailment even under High RE scenarios.

Figure ES4 Interstate electricity trading could reduce system costs further – average electricity cost per unit for a fully integrated India versus for an isolated Karnataka



Source: CPI analysis

The reality lies somewhere in between, and we have also modelled a system with interstate exchange levels similar to today's levels. This analysis indicates that only a small portion of the 7% further benefit is achieved given today's levels of integration, after all flexibility advantages have been factored in.

Connectivity will also alleviate the pressure on Karnataka's existing flexibility resources that without action will be insufficient to meet the state flexibility needs from the middle of 2020s and has the potential to add value to the state's excess capacity from solar generation. A state electricity system, well integrated with the rest of the national grid, under a HRE scenario also eliminates the need for expensive and carbon-intensive back-up diesel generation, figure ES4 above.

Finding 4. Developing appropriate market mechanisms to encourage the development of flexibility options is critical

In our report on electricity market development and flexibility options for India[5], we set out a series of actions that India should take related to electricity system market design to realize the cost, reliability, and environmental advantages of increasing flexibility for the Indian electricity system. These actions begin with developing comprehensive data to be used first in planning and implementation decisions and then as the basis for developing and implementing pricing systems. After data, we set out a series of actions around technology and infrastructure development, incentives, business models and market design. Most of the requirements at the India level are mirrored by needs in Karnataka, although differences in circumstances inevitably lead to different emphasis and focus. In Figure ES5 we set out the issues and systems/incentives that Karnataka should address in the short and long-term.

Taken together, these actions should put Karnataka on course for both a lower cost and cleaner electricity system, but the state would also be well positioned as an important participant and contributor to the development of improved operational resilience, reliability and resource adequacy for India's electricity system.

[5] ETC India Flexibility report - https://www.climatepolicyinitiative.org/wp-content/uploads/2020/08/CPI-India-flexibility-25-August-2020-full-report-1.pdf

Figure ES5 A market reform roadmap for developing a flexible, low carbon electricity system for Karnataka

<table>
<tr><th></th><th>Data

Develop, improve, disseminate</th><th>Technology

Develop, deploy, cost reduction</th><th>Infrastructure

Plan, finance, build</th><th>Awareness

Build and drive behaviour</th><th>Business Models

Facilitate development</th><th>Incentives

Provide and harmonize</th><th>Market Design

Improve and integrate</th></tr>
<tr><td>Flexibility from Demand
Develop, test, and roll out options</td><td rowspan="3">India and KA will benefit from a comprehensive ‘data mission’, focused on regular and systematic data collection, and maintaining databases on:
• Demand by end-use
• RE generation for each plant by 15-min block
• Powerplant capabilities, costs and generation profile by 15-min blocks
• Potential flexibility options and cost

This data would be essential input into building additional flexibility capacity and evaluating the value of options and programmes</td><td>KA could benefit from pilot programmes:
• Agricultural pumping – feeder separation vs solarization of pumps
• Commercial space cooling – automated access
• Cold storage
• EV charging models
• Industrial flexibility management – contracts vs incentives</td><td rowspan="3">KA needs to build out a measurement and energy management system that includes:
• Additional metering, including hourly and time of day metering
• Conduct expanded pilot programmes and Develop a smart metering system rollout for some customer groups
• Develop measurement, settlement, and pricing capabilities and IT infrastructure to support the new systems of market and incentives to support flexibility and integration</td><td>Build awareness among agriculture consumers re separate feeders vs solarization of pumps under KUSUM
Building awareness among industrial customers of flexibility opportunities and ways of accessing value

Develop awareness among space cooling consumers

Widespread information dissemination on programmes with involvement of local influencers</td><td colspan="2">Create expanded energy suppliers remit and build a competitive energy supplier industry

Create and negotiate daily, ramping and seasonal flexibility contracts with industry

Create and negotiate contracts for daily shifting with commercial cooling load

Pricing mechanism along with an incentive/ penalty for EV charging to encourage shifting of load from high demand periods to high generation periods</td><td rowspan="5">Develop a long-term model for the Karnataka electricity system design – potentially working with national players - that gives flexibility resource developers confidence in the future demand for flexibility services

Create transition markets that accelerate the development of flexibility options</td></tr>
<tr><td>Storage

Develop and install</td><td>Pilot programmes for battery storage:
• Substation/Grid
• Distribution system
• Backup/Diesel replacement
• Ramping assistance
• RE+ storage, especially small scale</td><td>Build awareness among owners of standby (diesel and storage) of opportunities to provide flexibility services</td><td colspan="2">Explore developing, fostering, or incentivizing Karnataka storage development/ manufacturing / operating companies – as part of KPCL and BESCOM as well as separate private developers</td></tr>
<tr><td>Powerplants

Encourage operation and regulatory changes and investment</td><td>Pilot programmes to assess costs and potential for each category of powerplants to:
• Lower minimum generation to improve ramping and shifting
• Two-shifting
• Seasonal operation of older plant units</td><td>Capacity building across industry and practitioners – Facilitate better understanding of opportunity to enhance system performance against impact on operating costs and plant reliability</td><td colspan="2">Amend thermal powerplant contracts to enable/ enhance potential offerings of flexibility and reward power plant owner/ operators for the value of services
Implement a new seasonal capacity mechanism

Shift existing coal to two-shifting and seasonal capacity</td></tr>
<tr><td>Transmission

Continue expanding with flexibility needs</td><td colspan="6">Karnataka should work with the national regulators to develop and improve interstate exchanges, transfers, and the related markets.
This work should include evaluation of options for ancillary service mechanisms.
KA should also be involved in national discussion on infrastructure build, transmission expansion, and development of pricing mechanisms such as financial transmission rights and locational pricing.
KA may wish to begin developing state level locational markets to improve intrastate flexibility and reduce state level distribution and transmission costs & constraints.</td></tr>
<tr><td>Integration

of options to minimize cost</td><td colspan="6">Karnataka will be one of the first states to experience significant issues with respect to flexibility, with certain challenges becoming apparent in the very near term and therefore should be a leader in pulling together a complete package of programmes.
KA should develop a comprehensive plan that includes incentives and markets for development of the options, alongside markets and infrastructure build-out that demonstrate a long-term commitment to increasing system flexibility and providing the mechanisms and incentives to optimize the integration of the options that develop.</td></tr>
</table>

1. Introduction

Karnataka is a critical player in India's target to install 175GW renewable capacity by 2022, and a further target of 450GW by 2030. In July 2019, over 50% of Karnataka's demand was met by solar and wind generation on three consecutive days, when 43% of the installed (and contracted) capacity came from renewable resources[6]. Capacity additions for generation will continue to be a political focus to support the economic development of the services sector in a state that has considerable agriculture demand.

Karnataka has a diverse portfolio of energy resources, with 9.5GW of existing thermal generation capacity, 5GW state-owned, 4.3GW contracted from IPPs, NLC and NTPC[7]. Over the last decade, the state has considered a number of coal, gas and hydro (including pumped hydro) powerplants, but a number of these plants are stalled for environmental reasons, or plans are still in the early stages. We share a summary of the status of these plants in Table 1.1.

Table 1.1 Overview of the powerplant pipeline and current status for Karnataka

Hydro projects	Capacity (MW)	Ownership	Status
Gundia Phase II	200	State	Stalled due to implementation of Yethnable drinking water scheme in the same catchment area
Shivasamudram RoR	200	State	Pre-feasibility Report (PFR) prepared by KPCL. S&I delayed due to local opposition
Gangavali Stage II (Bedthi)	400	State	
Kali Stage III	300	State	
Aghanashini (Tadri)	600	State	
Pumped Hydro projects	**Capacity (MW)**	**Ownership**	**Status**
Kali	600	State	PFR prepared by KPCL. S&I delayed by local opposition
Sharavathy	2,000	State	Project approved by Dept of Forest, Karnataka, and NBWL, KPCL to start geotechnical investigation and survey
Varahi	1,500	State	Survey and Investigation in progress
Coal-fired projects	**Capacity (MW)**	**Ownership**	**Status**
RTPS Stage II - Edlapur	800	State	No update since 2014
Gulbarga	1320	State	
Kadechur - Yadagiri Phase I	1320	Private	
Udupi (Adani) Phase II	1600	Private	PFR submitted, sought permission from MNRE, expected to come online by 2022.
Gas-fired projects	**Capacity (MW)**	**Ownership**	**Status**
Yehlanaka CCPP	370	State	Expected CoD – 2021
Bidadi CCPP	700	State	All clearances are obtained including MoEF. EPC tender stalled by court.
Tadadi CCPP	2100	State	PFR prepared and action has been taken for obtaining statutory clearances.

Source: Annual report SRPC, KPCL

[6] Clean Technica - https://cleantechnica.com/2019/07/22/solar-wind-met-over-50-of-an-indian-states-energy-demand-3-days-this-month/
[7] SRPC Annual report 2018-19

For our analysis, we have assumed that the 370MW Yehlanaka gas plant will reach COD by end-2021 and the 1.6GW Phase II of the Udupi supercritical plant will reach COD by 2030.

Karnataka benefits from 3.8GW of hydro capacity, including pumped hydro, the majority of which is available for grid balancing and flexibility services. Some 2.6GW of nuclear and biomass provide mostly baseload power. The state has already met its 2022 solar target, with 7.04GW of installed solar capacity, over one-fifth of India's total installations. Wind has seen a steadier growth and the state is well placed to meet its 2022 target of 6.2GW[8].

With the abundance of hydro for balancing capacity, Karnataka is able to integrate its renewable capacity and balance its grid. Meanwhile, thermal plants have seen their load factor fall during high renewable generation periods, driven in part by the high cost of coal procurement for Karnataka's coal plants (long distance to domestic coal mines, and imported coal).

This paper is a continuation of our previous work for both the Energy Transitions Commission (global) and ETC India, where we concluded that high levels of additional flexibility was paramount in delivering lower system costs for a high renewable, low carbon electricity system. This study follows from a similar one for Tamil Nadu, where we dug further to understand what kind of market transitions and reform steps would be required to deliver and integrate the state's flexibility needs. We now look at the flexibility options for Karnataka, how much they cost and what they will be worth to the overall development and operation of a low carbon system. This paper then looks at how market reform can help the state access and efficiently integrate this flexibility within its electricity system.

This paper is structured is structured as follows:

- **Section 2** lays out the methodology we applied in our analysis
- **Section 3** examines Karnataka's flexibility needs
- **Section 4** first summarises how the flexibility options for Karnataka come together into portfolios and what it means for costs, need for curtailment and CO_2 emissions. We then take a deep dive into each of the flexibility options – the potential and cost of flexibility options, what barriers exist to accessing their potential and the role of market reforms in resolving these
- **Section 5** is a transition roadmap for Karnataka, outlining what the state needs to do to deliver these options; either by maximising the potential of available options now and others that are necessary to plan for now to deliver by 2030.

[8] KPCL, 2020 - http://karnatakapower.com/en/generation/

2. Framework & methodology

Our evaluation of the market reforms required to put Karnataka's power system on a low-carbon pathway is based on our work looking at India's flexibility options and needs up to 2030[9], and uses a similar framework and methodology to our market reform case study for Tamil Nadu[10].

For Karnataka, the examination of flexibility needs and options are influenced by:

- High levels of solar, with less impact from the monsoon season;
- High electricity demand from agriculture;
- Relatively low levels of industrialisation;
- Overweight contribution from the state to India's overall GDP;
- Lack of in-state coal sources.

Our findings are based on the cost, resource potential of various electricity system flexibility options in Karnataka, and the barriers that exist in their development, including the integration of these options within the context of the state as well as the country. The cost and resource potential of flexibility depends on how demand and generation capabilities evolve. The barriers to their development are more widespread, spanning regulatory, technical, commercial, contractual, and behavioural drivers as well as lack of data and awareness. Our approach assesses the impact of potential flexibility options against realistic scenarios to estimate the value of flexibility, the priority options to be pursued as well as reforms to target these priorities.

The data for our models and analysis has been drawn from a combination of sources such as tariff orders, annual reports, regulatory guidelines, and various reports published by CEA, KERC, KPCL, SRPC and other electricity authorities in the state, with the generous contribution of historic demand data by POSOCO and historic generation data from Vasudha Foundation.

To fully understand the need and scope for electricity market reform in Karnataka, we asked the following questions:

1. **Challenges**. What are and will be in the future the most important challenges for the electricity system in Karnataka? How and why are they different than at the national level?
2. **Technology options**. What options can the technology/ business provide and what is the local need / market for these services?
3. **Cost**. What is the cost of delivering these services?
4. **Value**. What is the value of these services, compared to other options?
5. **Barriers**. What are the barriers or market development needs for these options?
6. **Market design implications**. How do these options relate to market design and development issues?

2.1 Renewable Energy Scenarios

For Karnataka, three different renewable energy scenarios have been considered.

- **Current trajectory scenario (CTS)** based on forecast of future renewable energy deployment following Karnataka's historical trends and growth rates.

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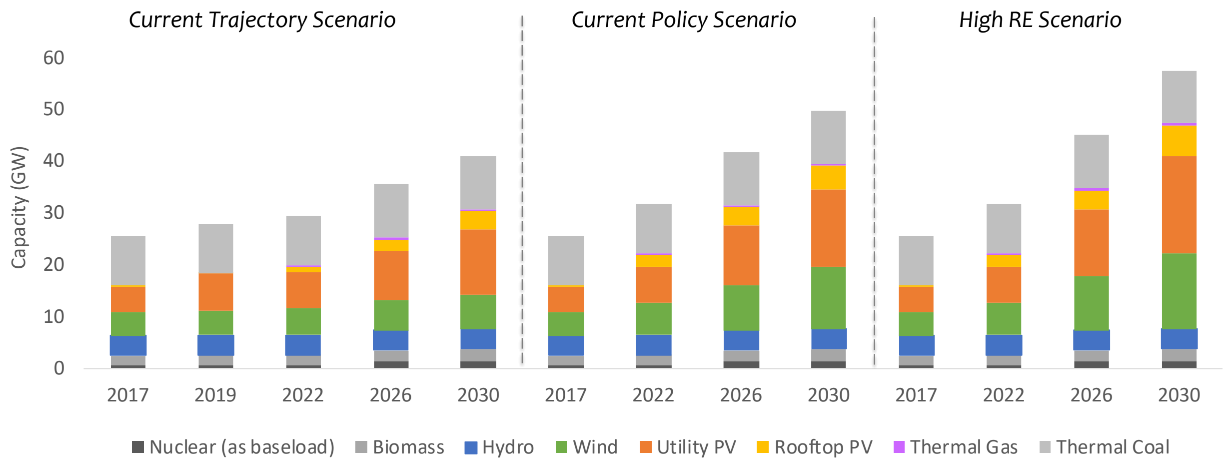
[9] ETC India flexibility report - https://www.climatepolicyinitiative.org/wp-content/uploads/2020/08/CPI-India-flexibility-25-August-2020-full-report-1.pdf

[10] Electricity Market reform – Tamil Nadu case study

- **Current Policy Scenario (CPS)** where Karnataka meets the state specific renewable energy deployment target for 2022 set by the Ministry of New and Renewable Energy (MNRE)[11], and continues to further add renewable capacity at the same rate to 2030.
- High renewable energy (HRE) assumes that India accelerates renewable energy deployment in line with increased climate mitigation objectives, ie, a national RE target of 450GW by 2030 with state distribution of the new renewable energy capacity in the same proportion as that in 2022 under the current policy scenario.

Figure 2.1 Renewable Energy Scenarios for Karnataka



Source: KPCL, CPI analysis

In each of the scenarios, Karnataka's nuclear capacity doubles in 2026, with another 700MW unit added at Kaiga. Hydro capacity is assumed to be constant across the decade. We assume 370MW of Yehlanka gas-fired capacity will be added in the near term and the 1.6GW Phase II expansion of the Udupi supercritical plant will reach COD by 2030. For the CPS and HRE scenarios, we have considered additional scenarios, eliminating the 1.6GW of coal pipeline.

2.2 Assessment of flexibility needs

For each of the three renewable energy scenarios, we assess the development of different flexibility needs between 2017 and 2030. The demand profile for 2017-18 was received from POSOCO. The demand profile for 2030-31 was based on the 2013-14[12] load profile, also received from POSOCO, scaled to match 19th EPS estimated energy requirement and load factor (2026-27 projected forward to 2030-31) at the same rate as historical CAGR.

The assessment is based on the analysis of Karnataka's load shape in a typical year and how it will be affected by changing usage patterns, analysis of system modelling, and application of local system operation guidelines. The flexibility requirements we have assessed include:

- **Short-term reserves** to meet sudden, unexpected changes in either supply or demand due to errors in scheduling, forecasting or forced outages.
- **Ramping** requirements where the limiting factor is not how much energy can be provided, but how fast the system can react to increasing (or decreasing) demand or decreasing supply (for example from solar PV) over a period of 15 minutes to three hours.

[11] As of 2018, Karnataka had already met its 2022 solar energy target of 7.04GW
[12] 2013-14 to align with the base year chosen by NREL for wind and solar production profile projection.

- **Daily balancing** to match excess production with higher demand at a different time in a 24-hour period. It analyzes the mismatch between the peaks and troughs of the demand curve against generation and the need to shift demand or generation resources to match the two.
- **Seasonal balancing** matches seasonal variation in generation patterns and demand and the flexibility to shift supply or demand across seasons and the year to maintain the required match of supply and demand across the year.

Due to the high proportion of solar PV, Karnataka requires special attention to its growing ramping and daily balancing needs, as production varies dramatically between sunrise and sunset, and the state's electricity system will require other resources to smooth out the drop in supply from solar at the end of the day. Currently, hydro plays a significant role in daily balancing.

2.3 Assessment of flexibility options

As a next step we looked at the potential and cost of flexibility options within three main categories:

- **Flexibility from demand**. The lowest cost opportunity, and the greatest uncertainty is the amount of flexibility that Karnataka can harness from demand. The lack of comprehensive end-use data on energy consumed, load patterns, price sensitivity, customer attitudes and other data needs prevents a complete analysis of demand potential. We have focused on developing preliminary estimates, that can help determine the role and potential importance of demand side flexibility, focusing on a sub-set of end-uses, agriculture pumping, EV charging, space cooling (commercial and domestic) and industrial demand. Capacities and growth have been calculated based on existing capacities, market data, current and projected growth. For each of the end uses, we estimate potential and use these as proxies to identify potential barriers and how market reform can remove these barriers and facilitate implementation.
- **Storage**. Batteries and other storage options can provide most of the flexibility service, but the cost of doing so is highly dependent on the capital cost of the battery systems (including balance of systems, EPC and operation costs), the full cycle efficiency and how long batteries last. In Karnataka, we found that apart from grid-level, behind the meter and co-location with utility scale solar projects, the state's focus on distributed solar creates opportunities to evaluate the feasibility and value of storage that is co-located with distributed solar agriculture pumps and rooftop systems.
- **Powerplant flexibility**. Most flexibility today is provided by Karnataka's 3.8GW hydro capacity and 5.2GW of state coal-fired generation. These plants are capable of delivering all types of flexibility. Although there are limits and costs associated with these resources. Operating thermal plants flexibly reduces plant efficiency, increases fuel costs and can increase operating costs, not all of it recoverable under standard contracts. Karnataka faces the additional challenge of high fuel costs for its coal-fired plants. To provide reserve, extra plant capacity needs to be built and kept online, again increasing costs. We compare these costs for each type of flexibility using incremental costs to deliver the service. Additionally, we have found that most plants on the Indian system, including Karnataka, can deliver more flexibility than they currently offer. Even without modification, experts suggest that the plants can offer more flexibility by changing operational practices. Retrofit investments can also significantly increase the amount of flexibility each plant can offer. We incorporated feedback from Siemens' studies on coal plants in India and feedback from the operations team at NTPC to evaluate the cost and potential of retrofits and to include those options in our system modelling.

We have focused here on identifying important categories of flexibility options rather than an exhaustive assessment of all resources for flexibility available to the state. As Karnataka develops market incentives and with proper market design, more flexibility options could develop, particularly more flexibility from demand. Hence, the analysis and benefits from flexibility are conservative, provided Karnataka can implement the programmes and market reform needed to develop the flexibility options.

2.4 Power system modelling and integrated portfolios

Supply curves

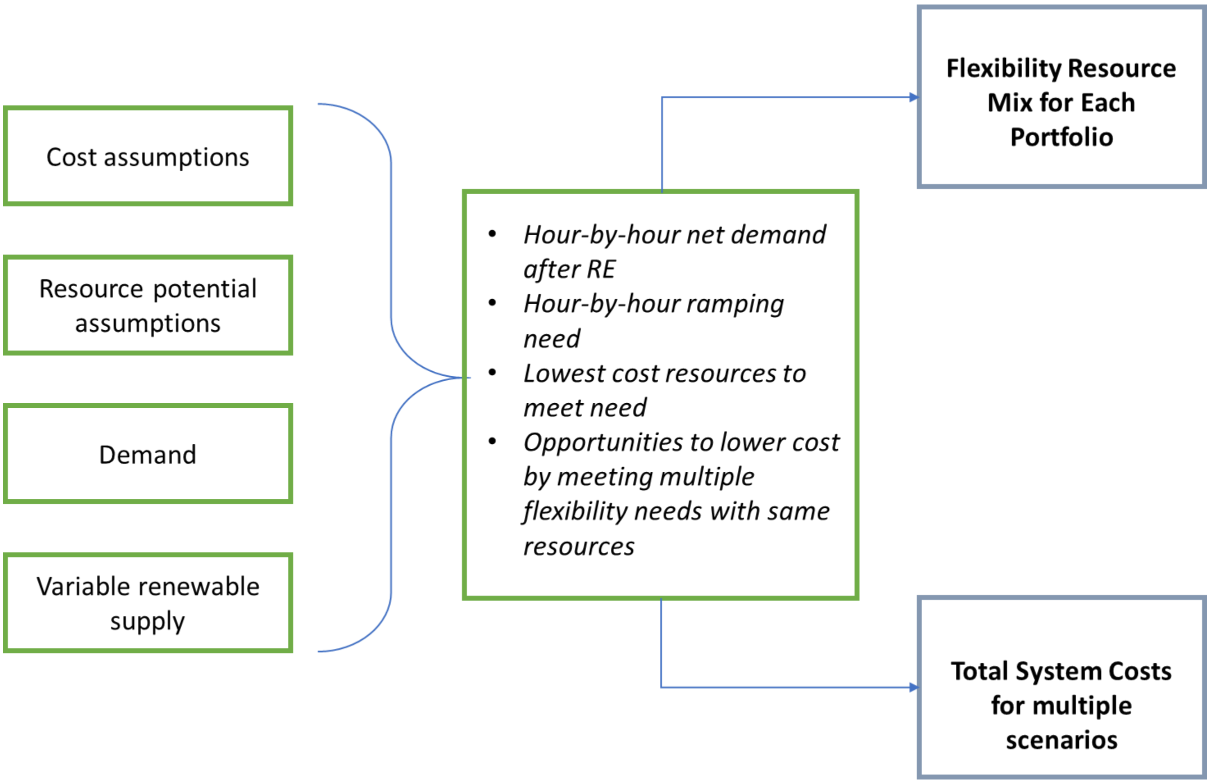
With the demand for flexibility established and a potential supply and cost for each of the flexibility needs, we are then in a position to model how these various flexibility options would work together in meeting India's electricity supply needs. To understand which options will be used, we put together a series of supply curves for each flexibility need, mapping the cost competitiveness of each flexibility option in providing each flexibility need, as shown later in section 4.

Power system models

Using our supply curves and forecasts for annual hourly load shapes for Karnataka, we evaluate the "dispatch" of different sets of flexibility options to meet various flexibility needs of the system. The aim is 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.

CPI Energy Finance has built its own power system model to understand the costs and dispatch of the Karnataka system for each of the three energy mixes and flexibility mixes, starting with a base case limited to existing flexibility resources, portfolios predominantly relying on procuring flexibility from demand, storage, powerplants, and a combined portfolio incorporating all flexibility options. More information on portfolios and their impacts on system costs and dispatch is shared in section 4.

Figure 2.2 Integrating assumptions into a power system model



While these are not complete system optimisation models, these models should provide results that are accurate within the constraints of the assumptions around load, costs, resource potential, renewable energy supply, weather conditions and so forth for 2030. Our model fits the various assumptions together in one model as depicted in the figure 2.2.

2.5 Barriers

There are considerable barriers to the development of flexibility resources and their adoption and integration. Barriers impact each of the potential resources differently but emanate from overlapping factors.

- **Data**. Lack of end use data makes it difficult to understand which consumers can shift their demand at reasonable cost, and which incentives will be most effective. Data gaps for individual powerplants makes it difficult to assess their flexibility potential, costs and trade-offs.
- **Technology**. With more flexibility options, metering, measurement, communication and settlement systems will be integral to monitoring, control, dispatch, incentives and planning. For example, to reduce the costs of storage and to create storage solutions specific to segmental needs.
- **Infrastructure.** Investment and planning are required to develop infrastructure, such as transmission to deliver flexibility where it is needed, when it is needed, or the IT and metering systems to schedule and integrate flexibility.
- **Awareness and behaviour**. Before any action can be taken, consumers and generators need to be aware of the opportunities for flexibility. Beyond that, programmes need to help change entrenched practices that have developed over many years.
- **Business models**. Developing new business models can have a very important role in reducing the costs of flexibility options and making growth and scale more accessible, enabling investors, consumers and other to monetize and benefit.
- **Incentives**. Incentives and markets need to operate at two levels, dispatch and optimisation as well as investment to align flexibility providers with system needs.

Current systems, operational practices and barriers for different technologies and options have been analysed using secondary research as well as stakeholder engagement within and outside Karnataka. These engagements helped us understand the institutional readiness to adapt to market reforms and the trade-offs in the context of Karnataka. For our recommendations, we also looked at successful international frameworks and projects, eg, case studies and interviews on battery storage systems across the the US and Australia by our team at Stanford University.

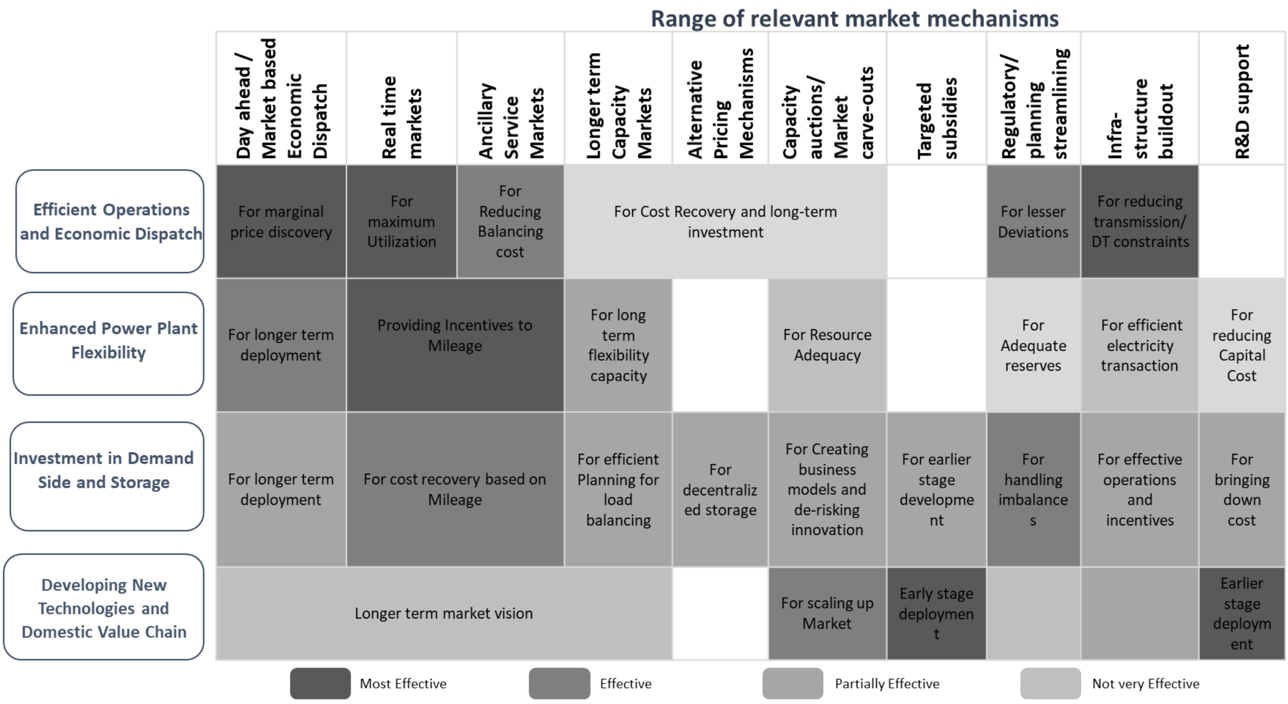
2.6 Role of market reforms

Karnataka can pursue ambitious renewable energy targets, but concerted action on barriers is essential. Our analysis has shown that flexibility reduces system costs and makes integrating clean energy cheaper. Thus, increasing flexibility is a no-regrets step for Karnataka. While developing more flexibility should be addressed urgently to reduce costs and improve the quality of electricity supply, the pathway is not as straightforward. Karnataka needs to develop new data and information, technology, behaviour, and market designs to develop flexibility efficiently and cost effectively.

A number of the current market structures, policy framework, business models and incentives are designed to support old supply and demand models for electricity. Transitioning to new behaviours, new market models and incentivizing the evolution of operational and financing models will require not just the creation of new pathways (eg, markets can find the right price for ancillary and balancing services, real-time markets, market aggregators and deployment of control and measurement infrastructure can facilitate demand side flexibility) but also the assessment of approaches to integrate flexibility and flexible operation within the scope of existing contracts and arrangements (eg, the adjustment of existing thermal generation contracts to compensate for the cost of flexible operations).

We evaluated a range of different market mechanisms (figure 2.3) for Karnataka to assess their application and effectiveness to remove barriers and integrate priority flexibility options. On the basis of this analysis, we put forward our recommendations in Section 6 for market reform and a transition roadmap for Karnataka.

Figure 2.3 Range of market mechanisms to develop and integrate flexibility options into Karnataka's electricity system



Source: CPI analysis

3. Karnataka's flexibility needs and challenges

Karnataka is the fourth largest economy in India, with agriculture, manufacturing and services contributing 10%, 26% and 64% respectively to the state's economy. Heavy industry is under-represented in the state, but Karnataka has the second largest though as yet unmodernised textile industry and a burgeoning services sector, fuelled by its incentives to attract the IT industry, which is expected to grow c.8% in 2020-21[13].

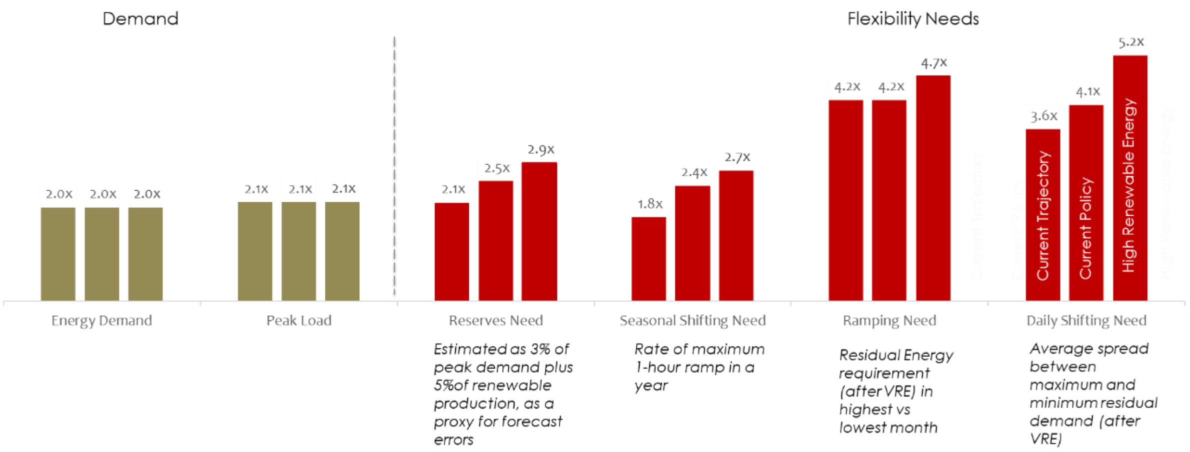
On the demand side, agriculture is the largest electricity consumer in Karnataka (38%), ahead of residential (22%) and industrial (19%). The overall growth in demand for Karnataka remains low at a CAGR of 3.5%, driven largely by the residential and agriculture sectors, each growing at c.8% over the last 5 years.[14]

Karnataka operates a diversified energy portfolio, with an increasing share of renewables. As of December 2019, the state had installed 14GW of renewable capacity excluding hydro – 7.2GW solar, 4.8GW wind and 1.9GW biomass. Thermal (coal and lignite) contributed a third of the installed capacity at 9.5GW.[15]

Solar and wind generation assets are largely owned by independent power producers (IPPs), Hydro is mostly owned by the state and coal capacity is split between state and inter-state generating stations. Karnataka's coal plants are heavily dependent on far-lying mines mines, from 250km to 1,200km away and imported coal, which serves around 23% of the generating assets, adding significant costs and uncertainty to its supply. Karnataka's thermal fleet runs at low average PLFs, a result of uncertain supply and high fuel costs for thermal powerplants and and cheaper renewable generation. Despite surplus energy in the system, Karnataka imported 7TWh of electricity in 2017-18. By 2027-28[16], this could mean that an additional 49TWh of in-state generation could be needed to avoid such imports.

In the absence of additional flexibility and the accompanying market reform to facilitate and integrate flexible resources, Karnataka could face high system costs and lower reliability because of the curtailment of must-run renewables, compensation for expensive thermal generation for capacity not called and, in spite of excess energy, costly purchases from the exchange during peak periods.

Figure 3.1 Growth in Karnataka's flexibility needs 2017 – 2030



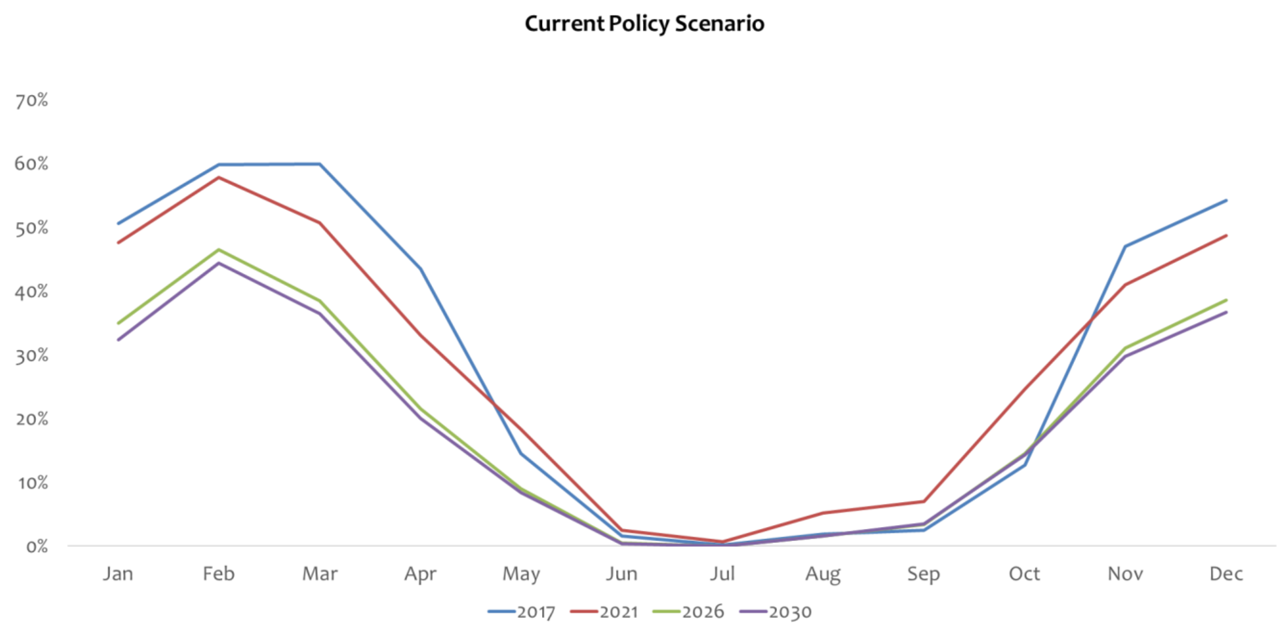
Source: CPI analysis

[13] Citation for https://www.prsindia.org/parliamenttrack/budgets/karnataka-budget-analysis-2020-21
[14] Annual report, SRPC, 2014-19
[15] Karnataka Power Corporation Limited
[16] Citation for www.thehindu.com/news/national/karnataka/coal-crunch-hits-thermal-power-generation/article20557326.ece

Over the next 10 years, Karnataka is expected to see a sharp acceleration in daily balancing and ramping needs, driven by the continued deployment of solar. By 2030, our analysis found that while demand and peak demand double, even under the most conservative renewable scenarios ramping requirements will grow at double the rate of demand and daily shifting need could increase 5.2x under the high renewable energy scenario (figure 3.1). Reserve needs and seasonal flexibility needs see a more modest increase with the HRE scenario at 2.9x and 2.7x.

In examining the challenges to Karnataka's future flexibility needs, we assessed the state's current and future energy demand and flexibility resources. Karnataka already manages the daily variation from its solar heavy portfolio by utilising its hydro plants, and to some extent coal plants, more flexibly. Our analysis shows that the residual load on the system, will reach close to zero during the high wind and hydro season, increasing the number of days with very low or even zero residual load for Karnataka over the next decade. The residual load of the system is the electricity demand after adjusting for generation from must run resources such as solar, wind, biomass and nuclear. This residual load/ demand is met using powerplants and if needed external procurement of electricity.

Figure 3.2 Monthly load factor of dispatchable plants – relative to peak net demand

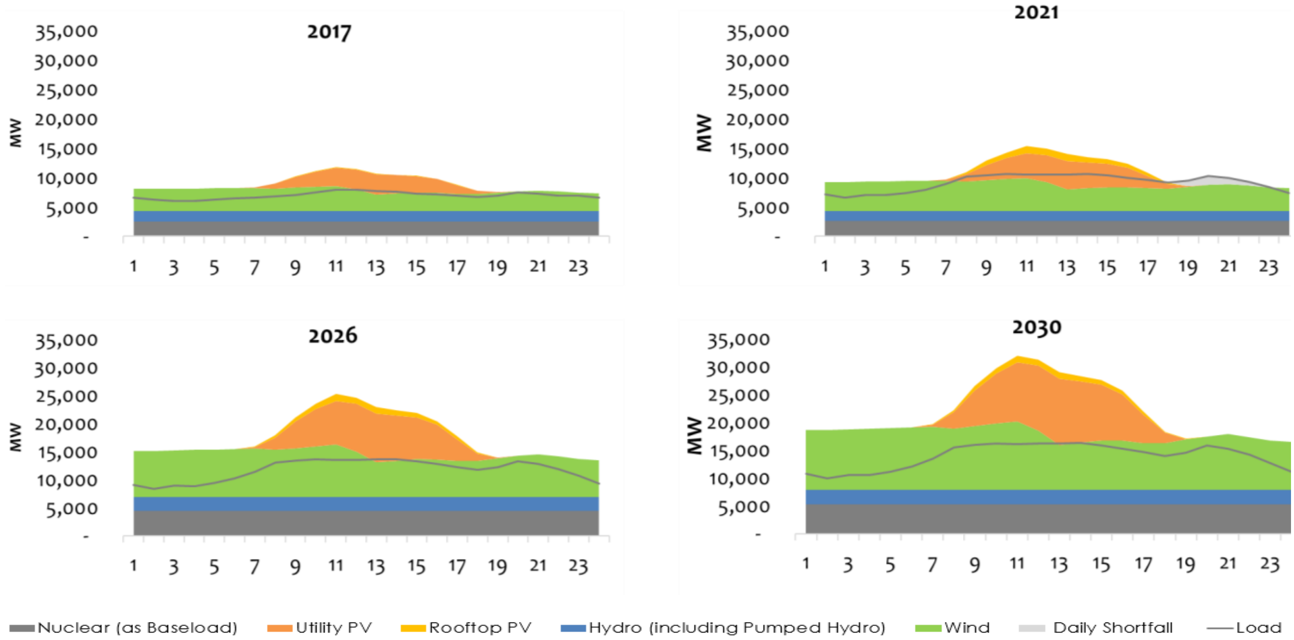


Source: CPI analysis

Over the next decade, this trajectory of excess energy will increase, posing challenges for grid balancing and system costs across the day and, as more wind is added into the system, during the monsoon season.

As more solar capacity is added to the system, Karnataka will generate more electricity. However, in the absence of any flexibility and integration measures, the mismatch of peak generation (solar hours) and peak demand (evening hours) will increase ramping and daily shifting. In fact, growth in solar energy is expected to shift (and to some extent has already shifted) maximum ramping requirements from the morning to the evening. Figure 3.3 below shows how daily balancing needs for Karnataka will increase over the next decade as the variability over the day and the excess energy production in the middle of the day will increase over time.

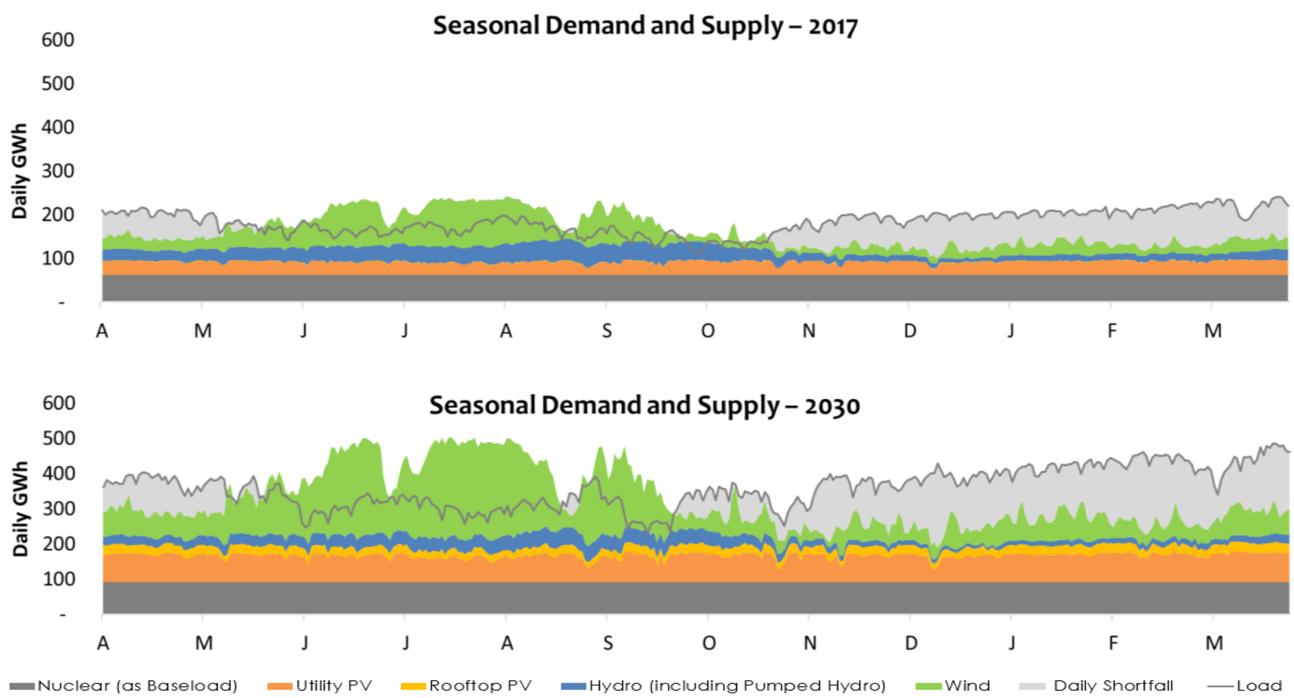
Figure 3.3 Growth of daily balancing needs for a typical day in the beginning of September – current policy scenario



Source: CPI analysis

Figure 3.4 below shows how during certain times of the year, renewable generation alone will be sufficient to meet all demand. At other times of the year, substantial amounts of energy from other resources will be needed. In the absence of sufficient flexibility and integration measures, this growth creates significant uncertainty for any resources in the state, and could impact the financing and investment costs of new resources in the state.

Figure 3.4 Growth in seasonal balancing needs – current policy scenario

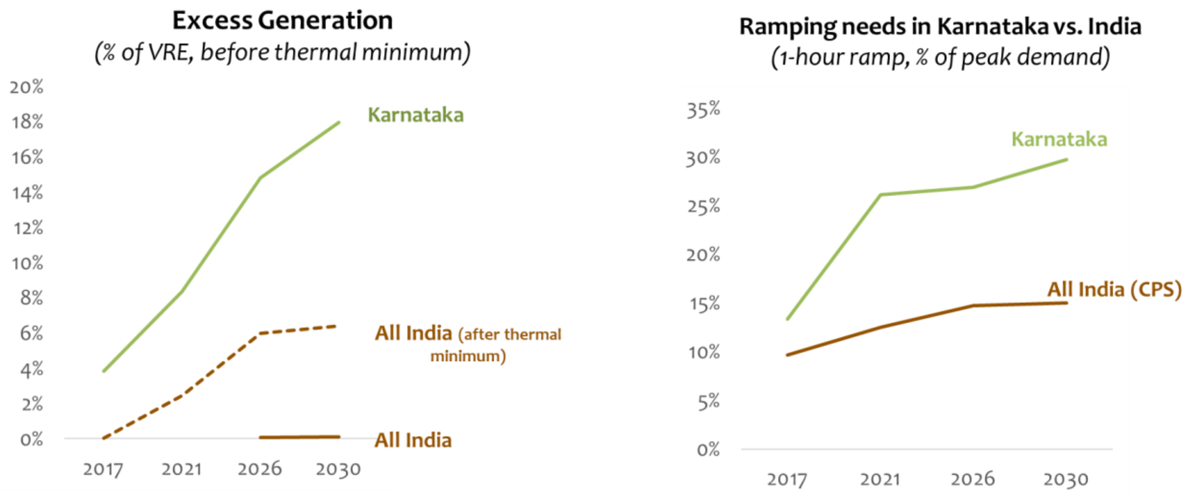


Source: CPI analysis

In addition to using its own hydro and coal portfolio, Karnataka also uses banking arrangements with other states by exchanging surpluses at different times of the year. But with a changing demand profile, and widespread growth in renewable generation across multiple states, options for such arrangements are likely to become limited without concrete efforts at integration, especially if transmission infrastructure lags behind.

Furthermore, we found that Karnataka's flexibility needs outpace those seen in India as whole (figure 3.5). In the absence of any flexibility planning, renewable energy could be curtailed by 15- 20% and ramping needs in the state could increase three-fold to 30% of the total peak demand, leading to strong variations in its daily load profile and without any route to cost recovery. Ramping needs may not be adequately met in the absence of sufficient flexibility capacity.

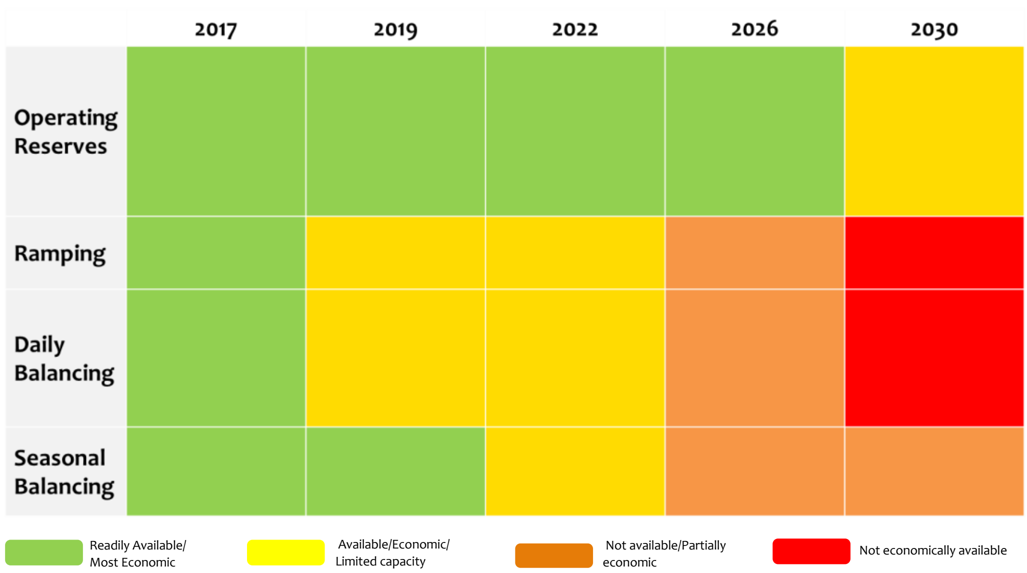
Figure 3.5 Even under current policy scenario, new resources will be needed before 2026



Source: CPI analysis

An initial assessment of the existing flexibility resources in Karnataka, and their ability to meet the state's flexibility needs under the High RE scenario suggests that strains are expected to be felt in the ability to meet each of the flexibility needs in the next few years. By mid of the decade, current flexibility resources for Karnataka will fall short of meeting all flexibility needs except operating reserves and these shortfalls could become critical by 2030 (figure 3.6 below).

Figure 3.6 Assessment of Karnataka's current electricity system's ability to deliver key types of flexibility (high RE scenario)



Source: CPI analysis

4. Meeting Karnataka's growing flexibility needs

Karnataka has many potential flexibility options that can be developed to meet its needs by 2030. Our analysis has focused on four main categories of resources:

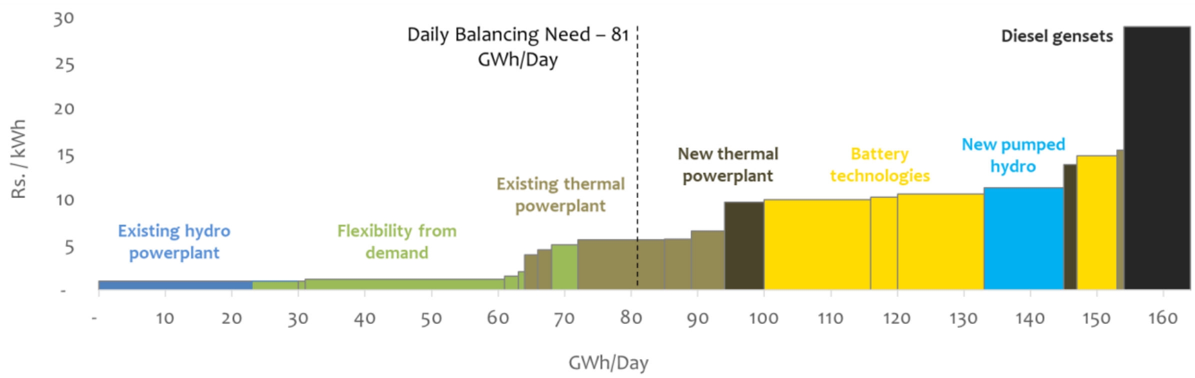
- **Flexibility from demand.** Agriculture, industrial, commercial and domestic sectors can all potentially modify their demand, changing either the volume or timing of electricity usage in response to market signals that could help the system match electricity supply to demand;
- **Storage.** Battery storage can shift demand or supply in ways that could help match electricity supply and demand, especially for intra day balancing needs;
- **Powerplant flexibility.** Technical, economic and contractual solutions can extend the flexible capacity of powerplants to meet variations in demand and renewable generation;
- **Import (or export) of low-cost flexibility resources from neighbouring states.** Other states, neighbouring or distant, if the transmission capacity is available, may have demand and generation profiles that are not correlated to Karnataka's – and thus reduce overall flexibility needs – or have access to flexibility from low-cost demand or powerplant resources that can reduce overall system costs. Accessing inter-state and national flexibility can provide value to Karnataka and across India, as outlined in Section 4.3. Our analysis does not do a deep dive into this resource which will require further development of interstate markets and incentives.

This analysis focuses on the market reforms and flexibility development efforts that Karnataka can take independently, or in anticipation, of national reforms. Thus our primary focus is on flexibility potential within the state. To establish the potential and requirements for flexibility driven market reform, we begin by estimating the potential and costs for each of the first three intrastate flexibility options in Karnataka and how that would evolve between 2017 and 2030.

To assess the potential and cost of meeting the flexibility needs, we created supply curves for each of the flexibility needs – daily balancing, ramping, reserves and seasonal balancing – the potential is represented by the width, the cost per unit by the height and the dotted line represents the projected flexibility need for 2030. Costs include variable costs, such as incentives to cover higher operating costs or higher fuel demand, as well as capital costs to cover equipment, upgrades and investments.

Figure 4.1 below shows one such supply curve for daily balancing need, where the width of the bar represents our estimate of the potential that could be available for Karnataka by 2030 and the height of the bar is the cost of meeting the daily balancing need by that particular resource, allocated to the kWh shifted over the course of the day.

Figure 4.1 Daily balancing supply curve for Karnataka in 2030



Source: CPI analysis

With a potential supply of over 160GWh/ Day and demand of 81GWh/ Day, this flexibility need is well covered. For daily balancing, existing hydro and flexibility from demand represents the cheapest options, however cheaper existing thermal powerplants are also needed to meet the shifting need. If resources for flexibility from demand are not fully developed in time, almost all of the thermal powerplant capacity would be required.

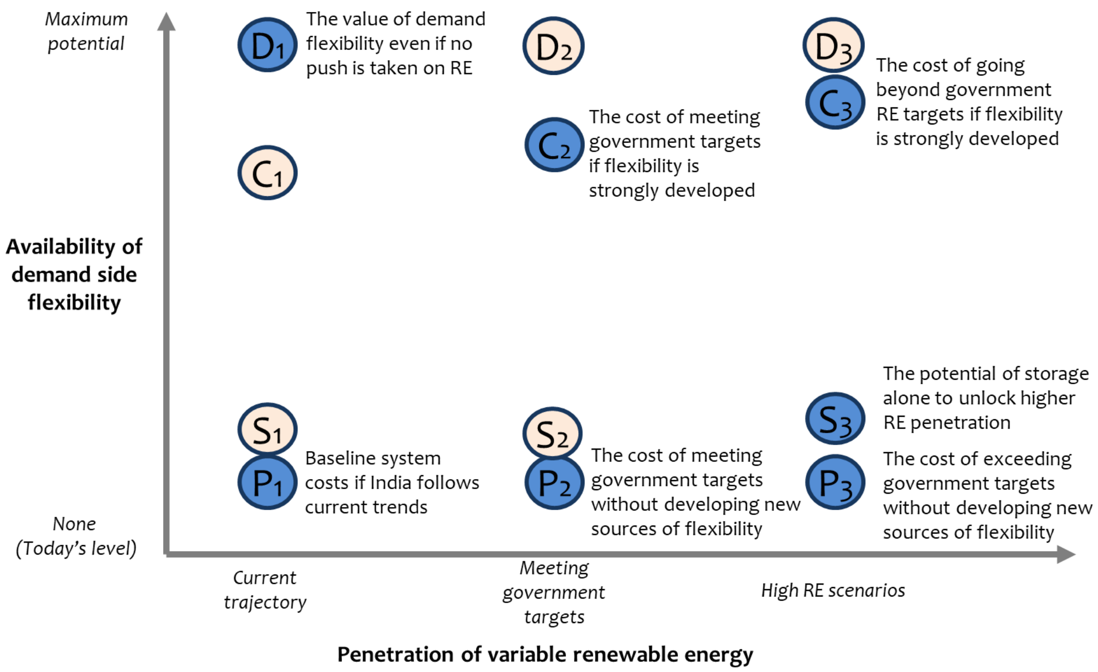
In this section, we look at how Karnataka's flexibility needs can be met effectively by bringing together the range of flexible resources and combining them into portfolios. The inputs and assumptions for the cost and the potential, and market reform implications for each of the resources individually are covered in detail in section 5.

4.1 Flexibility portfolios

An electricity system's flexibility resources are not a series of independent markets, rather they are linked together to meet the overall system requirements. Thus, to understand which options will be used, and how procuring these options will impact total system costs, we have combined flexibility resources into portfolios of options, using supply curves as a guide, and then we have used these options to calculate the total system cost over the course of a full year's hourly demand profile.

To some degree, both the amount of renewable energy and the amount of demand flexibility are variables that policymakers can influence. Since these two variables are also the key determinants of system costs and the cost and development of flexibility, our portfolios have been designed to test how each of these two variables will affect flexibility options and cost.

Figure 4.2 Portfolios built to assess the impact of demand flexibility and RE ambition



Our portfolios fall into four categories:

- **P. Powerplant driven portfolios** – System flexibility is provided entirely by hydro and thermal powerplants. Plants are upgraded and newly retired plants retrofitted if needed and economic to do so
- **D. Demand side driven portfolios** – System flexibility is provided by existing sources of flexibility and combined with flexibility from demand

S. **Storage driven portfolios** – System flexibility is provided by existing resources of flexibility combined with storage options
C. **Balanced portfolios of all options** – System flexibility is met with a combination of all flexibility options to determine which options would be used and at what scale to meet the needs at the lowest cost along with highest reliability of supply

In figure 4.3, we compared different flexibility portfolios above for each of the three renewable energy scenarios in 2030, starting from a base case, where current resources and approach to flexibility are maintained, without any market changes, flexibility development, action or planning. Using these baseline figures, we then looked at the impact on excess energy, average system electricity costs and CO2 emissions in portfolios that rely predominantly on enhanced powerplant flexibility, storage, demand flexibility, or a combination of all three to meet flexibility needs.

In each case, we estimate the economic cost of any load shedding or electricity shortfalls by assuming that captive diesel gensets would make up the shortfall where necessary. The cost of meeting load shedding shortfalls when no additional flexibility is added constitutes 5-15% of the total system cost, varying the base case across each of the three scenarios. Our experience shows that this assumption is conservative, as it might underestimate the cost of lost productivity, as well as capital investments and operating changes made in response to the risk of load shedding.

Figure 4.3 Balanced portfolio of demand, storage and powerplant flexibility perform best on most metrics and are least risky

Current Trajectory Scenario

	Excess	Cost	CO2
Base	13.25%	5.52	0.469
Fossil	-17.8%	-1.8%	-2.1%
Storage	-78.3%	-2.8%	-11.1%
DR	-81.1%	-7.3%	-13.6%
Portfolio	-85.5%	-8.8%	-19.0%

Current Policy Scenario

	Excess	Cost	CO2
Base	20.94%	5.064	0.345
Fossil	-7.74%	2.3%	-2.90%
Storage	-41.60%	-0.4%	-15.07%
DR	-48.19%	-5.7%	-21.45%
Portfolio	-58.64%	-6.2%	-24.06%

High Renewable Energy Scenario

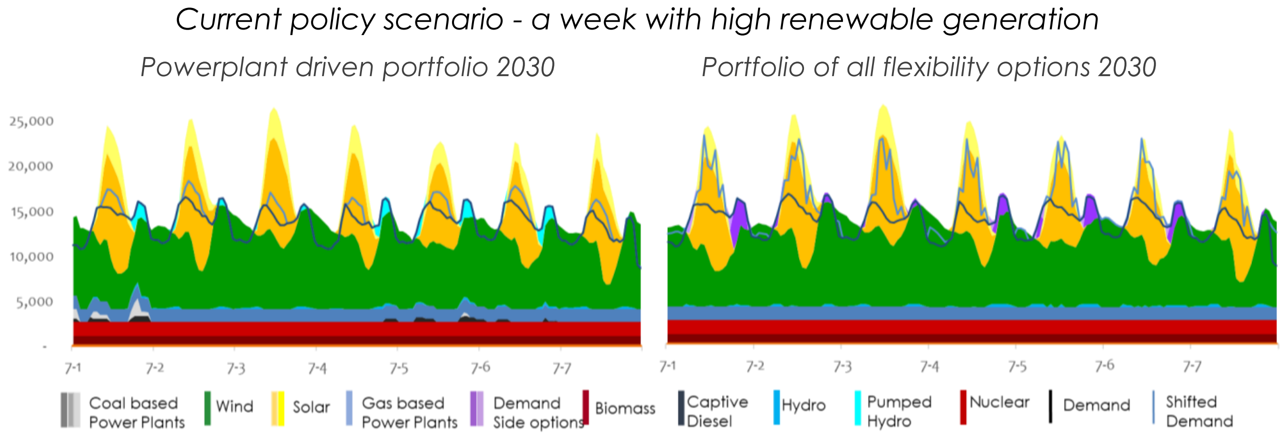
	Excess	Cost	CO2
Base	28.63%	5.09	0.289
Fossil	-4.9%	-2.2%	-4.2%
Storage	-27.0%	-1.0%	-17.6%
DR	-45.8%	-5.6%	-33.6%
Portfolio	-52.3%	-5.2%	-36.3%

Source: CPI analysis

The average total system cost (in today's money) is lowest for balanced portfolios, for all renewable scenarios, with the High RE with flexible portfolio system cost (Rs. 4.8/kWh) lower than the Current Trajectory with flexible portfolio system cost (Rs. 5.0/kWh).

Another perspective would be to look at how generation profiles and renewable energy curtailment affect the dispatch of powerplant across a day, week or year. Below, we examine how the mix of generation and flexibility resources would fit together in two different weeks in 2030.

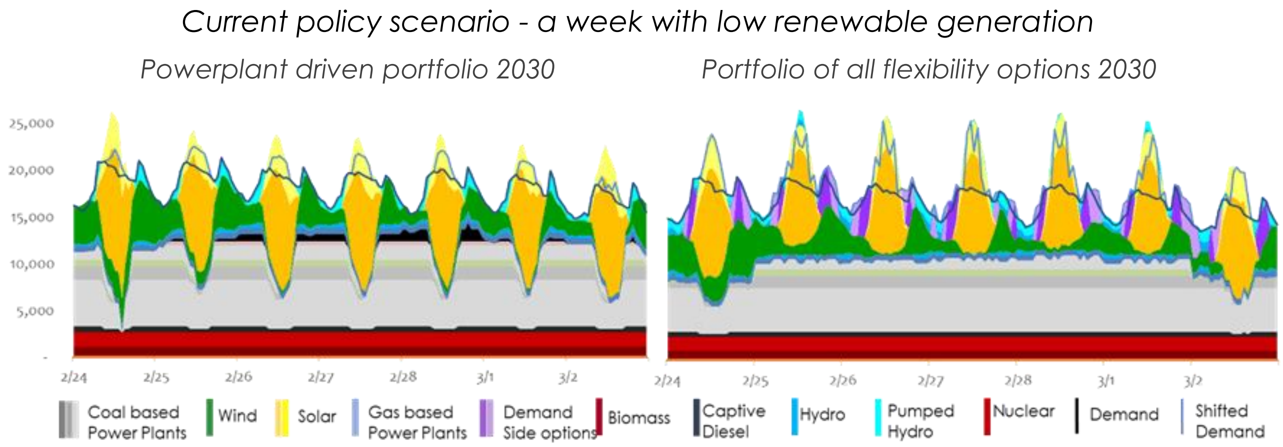
Figure 4.4 Portfolio of flexibility options allow more efficient operation



Source: CPI analysis

Figure 4.4 above looks at a week during the high wind monsoon season of July. In this sample week, generation from must-run capacity (nuclear, biomass, wind and solar) and minimum hydro exceeds demand (shown by the black line) during many hours of the day, with select hours showing the need for generation from other sources. Thermal powerplants have PLFs close to zero during the day and sometimes throughout the day. The left chart includes only powerplant flexibility options while the right chart includes all three flexibility options. The black line represents the pre-flexibility load profile that needs to be met across the week whereas the blue line reflects the load profile after demand shifting. Note how in the left-hand chart (powerplant flexibility only) there is a considerable amount of wind and solar energy above the blue line, that will be curtailed. That energy is wasted. We also note that coal-fired powerplants (in grey shades) need to vary their generation across the day and where called upon seem to only be required for a few hours. On the right-hand chart, more of the excess energy from wind and solar generation is either stored or used by demand shifted from other times of the day and no coal powerplants are turned on.

Figure 4.5 Portfolio of flexibility options allow more efficient operation



Source: CPI analysis

Figure 4.5 above looks at a week during the low wind and hydro season in February. During this week, the generation from must-run capacity is significantly reduced, requiring higher generation from powerplants – hydro as well as thermal. Note that in the left chart (powerplant flexibility only) there is high PLF required of coal plants, with additional generation required from back-up diesel genset capacity on some days. We also note that coal-fired powerplants (in grey shades) need to vary their generation across the day with some plants requiring two-shift operating schedules. On the right-hand side significantly more of the excess energy from wind, solar and thermal generation is either stored or used by demand shifted from other times of the day and powerplants operate more continuously, albeit with lower utilization.

4.2 Flexibility portfolios and the impact of reducing Karnataka's coal pipeline

For our analysis we also explored the electricity system of Karnataka without any further deployment of coal-fired powerplants, ie, removing the 1.6GW of supercritical coal-fired Phase II development expected at Udupi from the 2030 installed capacity. Figure 4.6 below shows the impact on the CPS and HRE portfolios without this coal pipeline. The costs in the base case increase marginally in both scenarios, driven by the costs of the shortfall being met by expensive diesel gensets. However, as we add more flexibility across these scenarios, we see higher savings in system costs, and similar trends in the need for curtailment and CO2 emission reductions, as with coal pipeline scenarios. These results indicate Karnataka's potential to decarbonize its electricity system more cheaply and more efficiently than policymakers may currently assume is economically and operationally feasible as we see that without any coal pipeline, the benefits for curtailment, costs and CO2 reductions are as good, if not better, in some cases, when flexibility is factored in.

Figure 4.6: With flexibility, Karnataka can pursue its low carbon pathway without the need to add any more powerplant capacity

With 1.6GW Coal Pipeline

Current Trajectory Scenario

	Excess	Cost	CO2
Base	13.25%	5.52	0.469
Fossil	-17.8%	-1.8%	-2.1%
Storage	-78.3%	-2.8%	-11.1%
DR	-81.1%	-7.3%	-13.6%
Portfolio	-85.5%	-8.8%	-19.0%

Current Policy Scenario

	Excess	Cost	CO2
Base	20.94%	5.064	0.345
Fossil	-7.74%	2.3%	-2.90%
Storage	-41.60%	-0.4%	-15.07%
DR	-48.19%	-5.7%	-21.45%
Portfolio	-58.64%	-6.2%	-24.06%

High Renewable Energy Scenario

	Excess	Cost	CO2
Base	28.63%	5.09	0.289
Fossil	-4.9%	-2.2%	-4.2%
Storage	-27.0%	-1.0%	-17.6%
DR	-45.8%	-5.6%	-33.6%
Portfolio	-52.3%	-5.2%	-36.3%

Without any Coal Pipeline

Current Policy Scenario

	Excess	Cost	CO2
Base	20.33%	5.34	0.338
Fossil	-6.7%	-0.9%	-2.37%
Storage	-41.0%	-3.4%	-14.50%
DR	-47.8%	-9.1%	-21.01%
Portfolio	-59.0%	-10.0%	-23.37%

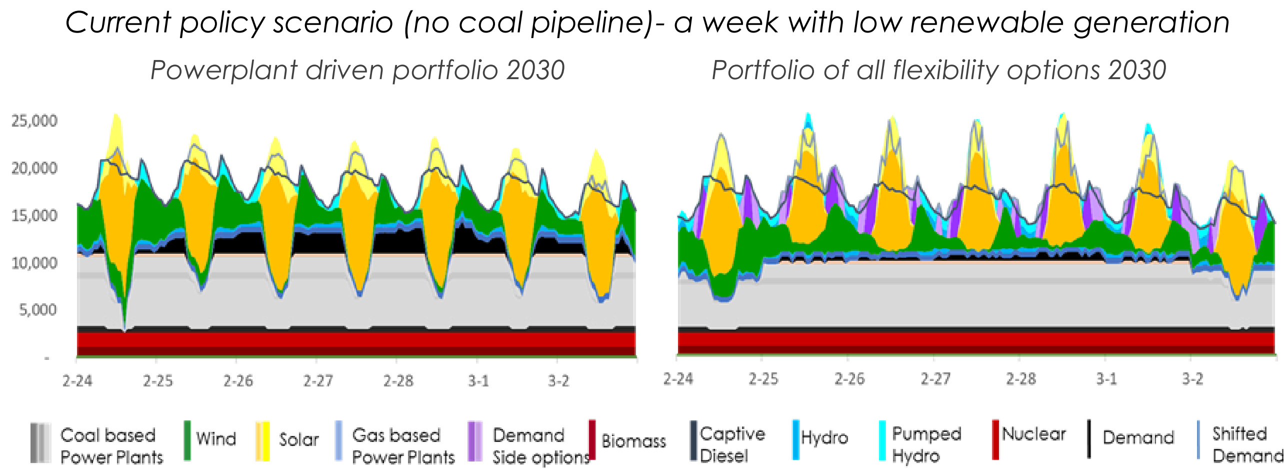
High Renewable Energy Scenario

	Excess	Cost	CO2
Base	28.17%	5.24	0.282
Fossil	-3.9%	-3.5%	-2.8%
Storage	-31.5%	-3.0%	-18.8%
DR	-45.4%	-9.5%	-32.6%
Portfolio	-50.4%	-9.6%	-34.0%

Source: CPI analysis

In figure 4.7, we take a look again at the week during low renewable generation season in February, under the modified CPS scenario (with no coal pipeline). We can see the lower generation from coal-fired plants as compared to figure 4.5. In the left-hand graph (powerplant flexibility only), the variability in the generation from coal-fired plants reduces, but the need to access back up diesel gensets increases during the low solar generation hours of the day. In contrast, on the right-hand side, thermal plants show minimal variability in their generation across the day and the need for back-up capacity is minimal, even without the 1.6GW Udupi Phase II pipeline capacity, due to shifting of both demand and supply.

Figure 4.7 Portfolio of flexibility options allow more efficient operation



Source: CPI analysis

4.3 Additional value for Karnataka, interstate markets and transmission

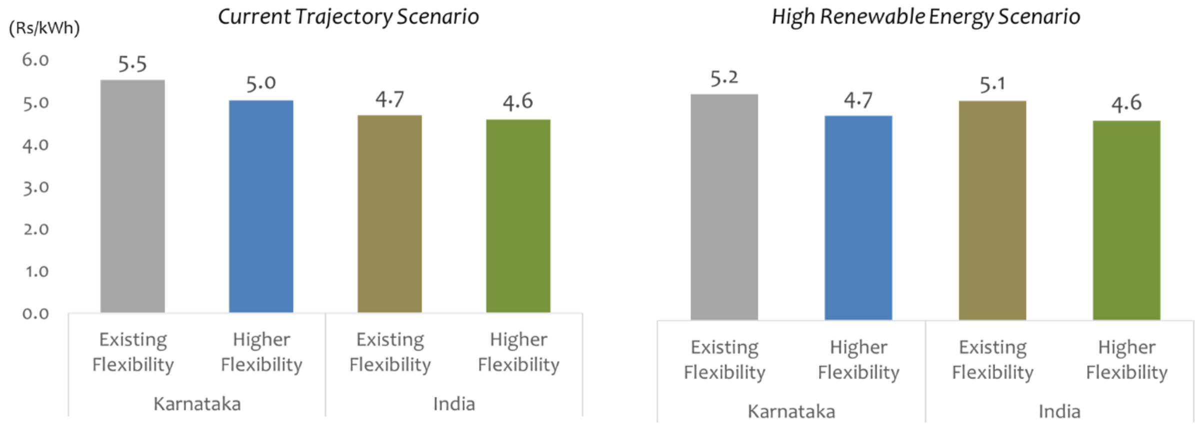
Our analysis considers Karnataka as a self-contained electricity system, without energy imports or exports from neighbouring states. The results demonstrate the potential benefits for Karnataka in developing its own flexibility resources and market mechanisms to incentivise the development and integration of these resources within the state electricity system.

One crucial question is the extent to which increased interstate flexibility trading, national flexibility and electricity markets could provide the same flexibility at even lower costs. Developing precise estimates of the impact on Karnataka would require similar analyses across each of the neighbouring states in India, as well as detailed transmission capacity and power flow modelling. Given the uncertainty around how each of the flexibility options will develop, this level of modelling would likely provide only a modest degree of additional information. In our modelling, however, we have also evaluated the impact of interstate electricity and flexibility transfers at levels similar to what we see today. The result is up to 7% additional cost savings for the high renewable scenario with no coal pipeline.

One simplified way to estimate the potential of interstate flexibility markets on Karnataka is to return to our modelling of India as a single electricity system without transmission constraints and access to markets for electricity and flexibility, for both demand and supply, across India[17]. Figure 4.8 shows first that integration could provide significant value under both the CTS and HRE scenarios. Complete integration would reduce system costs by up to 12%, without additional flexibility. Greater flexibility can be a partial substitute for greater integration, thus, with higher levels of flexibility the benefits of national integration fall to between 5-7%.

[17] Developing a roadmap to a flexible, low-carbon Indian electricity system, March 2020

Figure 4.8 Average system cost for electricity supply in Karnataka and India, 2030



Source: CPI analysis

Even complete integration is unlikely to provide all of the benefits suggested by this comparison. Differential transmission losses could raise Karnataka system costs, regardless of the level of integration, while transmission capex and system integration costs could further erode benefits. Notwithstanding, there is likely to be significant benefit from greater integration. The analysis suggests that markets at the state level in Karnataka can provide much of the cost reduction from more efficient system operation and flexibility enhancement, while benefiting from the relative ease of working with market development and policy within a single state jurisdiction.

5. Flexibility resources, potential, costs, barriers and market reform

In the previous section, we set out how the three main flexibility options could be used to develop flexibility portfolios to help Karnataka transition to a low-carbon and economically efficient electricity system.

In this section, we assess each of the flexibility options individually to understand the role that they can play in the future of the electricity sector in Karnataka and to establish the potential and costs for each of the options. We then examine barriers, both existing and expected that can potentially delay or limit Karnataka's ability to develop and fully harness these options, for example current contractual structures incentivising coal plants to operate as base load alone, with only a partial access to cost recovery for flexibility services provided.

Having established their importance and the barriers to their delivery, we look at the market reform that will be required to smooth Karnataka's transition, to overcome barriers, from the lack of the necessary technology, to current contracts and operational practices, to the lack of awareness and incentives.

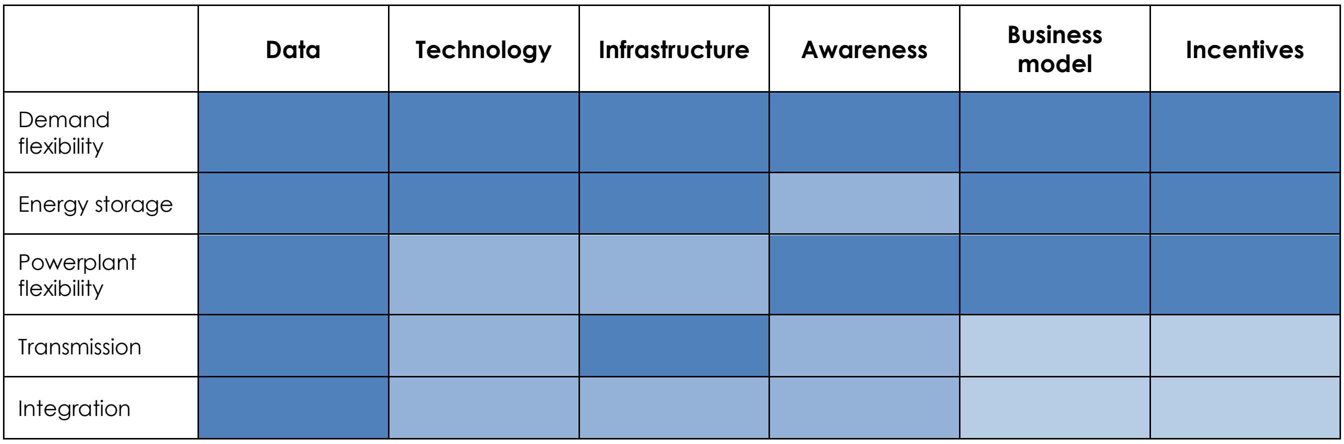
Some transitions can be targeted immediately whereas others will need to be planned for, with policy interventions that can pave the way for the resources, investments and discovery of business models to deliver the flexibility options for when they are most urgent and needed by Karnataka.

As we can see from figure 5.1 below, the more significant the impact and long-term the benefits, the more challenging the barriers may be to overcome. For example, with relatively minor adjustments to reduce the mandated technical operating minimums from 55% to 40% thermal power plants could provide 15% more flexible capacity that could be used for daily shifting. Such operational changes could have immediate impacts, but the overall contribution would be moderate. Policymakers may have other motivations to amend operating mandates, for example, by viewing the increase in flexible capacity from thermal assets as an opportunity to make the existing thermal fleet operate more efficiently and optimise their use in the context of decarbonisation goals.

On the other hand, demand flexibility incentives may be more challenging to implement, but they will have long-term impact on lowering costs of a system driven by intermittent wind and solar and enable that system to integrate more renewable energy onto the grid.

Therefore, a well-coordinated two-step approach will be required from policymakers to take up the quick wins to accelerate the transition today, and the longer-term interventions that help create the right conditions for electricity markets based on flexible, low carbon resources.

Figure 5.1 Priority areas for market reform and transition across six main barriers



Source: CPI insights

5.1 Meeting Karnataka's flexibility needs from demand

In principle, flexibility from demand is incentivising consumers to alter their consumption, either the size of consumption or its timing or both. Flexibility from demand could offer some of the lowest cost options to meet Karnataka's growing flexibility needs however, compared to using flexibility from storage or powerplants, flexibility from demand is both less developed and conceptually less well understood. As a result, useful share of low-cost flexibility from demand will take time, and its potential scale is significantly more uncertain than powerplants or storage.

In Karnataka, agriculture pumping, space cooling and industry are the primary sources of demand today considered for flexibility services, adding EV charging over the next few years as the state's EV fleet expands. Existing captive diesel generation can help meet daily balancing needs when demand exceeds supply.

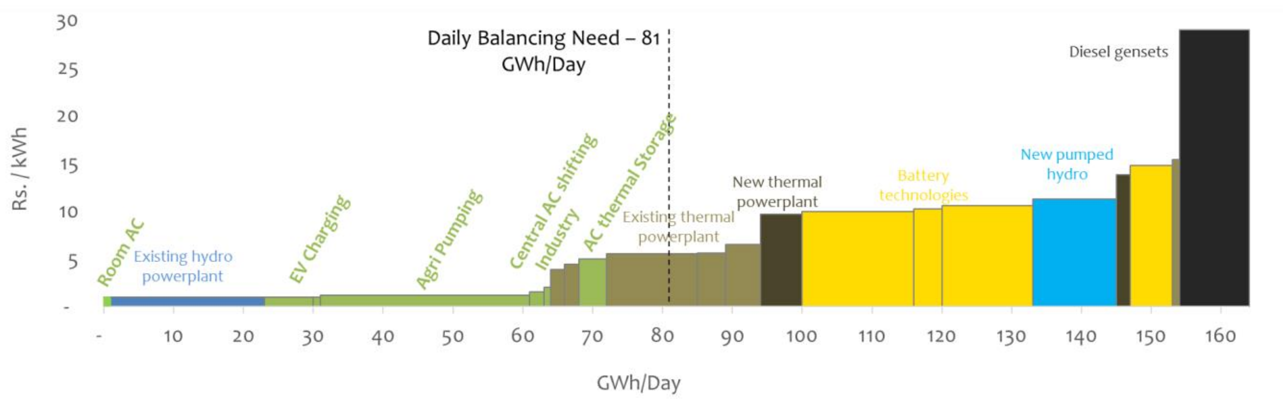
We estimate that 10GW of demand can be used flexibly today, a figure that we forecast could double to 20GW by 2030 from:

- **Agriculture pumping** represents over one-third of the demand in Karnataka and flexible operation of pumping provides a low-cost opportunity for flexibility, but one that requires completion of the current programme of separation of agricultural feeders and solarization of pumps in select areas, new metering and pricing schemes and control systems.
- **EV charging** presents one of the cheapest forms of flexibility across many balancing needs, but access to this flexibility will require careful development of business models, charging infrastructure and incentives with real time pricing.
- **Space cooling** is a third option with a high potential for meeting reserves and ramping needs, given the rapid growth forecast for cooling demand, but one that requires especially designed incentives and metering to change behaviour
- **Industry** consumes a little under 20% of Karnataka's electricity supply and besides participation in the ramping and daily shifting, provides a low-cost option for seasonal load shifting by improving incentives to manage maintenance periods or production schedules.

When combined, flexibility from these demand sources provide the lowest cost options for daily balancing, for example by 2030, as shown in figure 5.2 below.

Figure 5.2 Flexibility from demand provide the lowest cost options for daily balancing

Daily balancing supply curve 2030



Source: CPI analysis

5.1.1 POTENTIAL FOR FLEXIBILITY FROM DEMAND FOR KARNATAKA

The potential for flexibility from demand depends on who the consumer is and what they are using the energy for. Consumers must see the cost of a particular energy use as being significant enough to bother with and must see easy and convenient ways to provide the flexibility. Each of the evaluated demand sources, agriculture pumping, EV charging, space cooling and industry, have different potentials for addressing specific flexibility needs (Table 5.3)

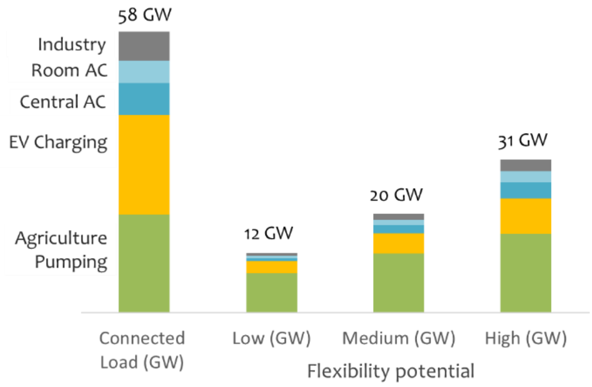
Figure 5.3 Demand sources, as they are added can be harnessed to meet different flexibility needs for Karnataka's electricity system

		Agriculture pumping	Electric vehicles	Space cooling	Industry*
Potential Connected Load**	**2017**	14.2 GW	0.2 GW	4.6 GW	2.7 GW
	2030	20.4 GW	20.2 GW	11.3 GW	6.0 GW
Spinning and Load Following		Upon separation, the agri feeders can be temporarily turned off to reduce immediate load	Can provide spinning capacity through v2g operations for charger connected vehicles.	Limited spinning and load following capabilities by turning off equipment chillers for a few minutes, automated DR	Limited spinning and load following capabilities by turning off equipment chillers for a few minutes, automated DR
Short Term Reserve			Temporary interrupting charging with appropriate price incentives to the vehicle owner/operator	Smart Air-Conditioners (ACs) and Smart plugs can shut down the compressor to free up MWs	Smart Air-Conditioners (ACs) and Smart can shut down the compressor to free up MWs
Ramping		Supplying agri feeders during the peak generation or low demand periods can reduce ramping needs	Charging vehicles during high generation and off peak consumption hours can reduce addl. ramping needs	Central AC load may be shifted to off peak hours using thermal storage or temperature raising in central AC .	Central AC load may be shifted to off peak hours using thermal storage or temperature raising in a central AC .
Intraday Balancing		With segregation of feeders, pumping can be shifted to off peak hours	Charging of the batteries during off peak hours	Central Air-Conditioners with thermal energy storage can shift peak cooling load to off peak	Shifting batch manufacturing activities to off peak times from peak hours provide Intraday balancing
Seasonal Flexibility		Contributes to the need for seasonal flexibility	PHEVs have some potential to provide seasonal flexibility by shifting to gasoline based operations during high peak months	May contribute to local needs for seasonal flexibility	Can schedule planned outages and maintenance to periods of high demand/low generation Select industries can be contracted for seasonal load shifting at a cost

*Including captive capacity; ** non-coincident capacity of equipment

Altogether, these sector combinations represent a peak load of 58GW, with between 12 to 31GW capable of being operated flexibly (figure 5.4). Agricultural pumping and EV charging make the largest contribution to daily shifting needs. Industrial load shifting across seasons through maintenance scheduling and adjustments in production schedules across the year could help manage seasonal balancing needs for Karnataka.

Figure 5.4 Potential for flexibility from demand in Karnataka



2030 Flexibility	Operating Reserves	Ramping Flexibility	Daily Flexibility	Seasonal Flexibility
Industry	600 MW	600 MW/hr	1.2 GWh/ Day	15 TWh/Year
Space Cooling	1,132 MW	1,132 MW/hr	2.3 GWh/ Day	-
EV Charging	5,100 MW	5,100 MW/hr	30.6 GWh/ Day	-
Agriculture Pumping	5,050 MW	5,050 MW/hr	30.3 GWh/ Day	-

Source: CPI analysis

The development of flexibility from demand to meet Karnataka's flexibility needs requires clear incentives, investment in infrastructure and policy interventions. For instance, incentives could encourage consumers to invest in insulation that would enable shifting in air conditioning timing, adoption of thermal energy storage for commercial cooling or shifting the times when agricultural pumping is used. Many countries have adopted mechanisms such as time-of-use pricing, real-time pricing and demand management through direct access. However, for such systems to be effective, advanced information and technology, automated control systems and communication equipment are required so that consumers can respond to price signals and sign-up agreements with utilities or third-party providers for voluntary demand reduction (figure 5.1).

Table 5.1 Flexibility from demand has low hanging fruits which can be tapped at relatively low cost

	Costs	Areas needing investment
Agricultural pumping	Rs. 13,000 / kW (derived from cost per connection)	• Dedicated agricultural feeders • Grid connected solar pumps under KUSUM scheme • Distribution monitoring and automation systems
EV charging	Rs. 5,000-10,000 / kW upfront cost Ongoing cost of < Rs. 700 kW-yr	• Chargers with Time of Day (ToD) / Time of Use (ToU) metering • Additional batteries to enable battery swapping for 2- and 3- wheelers • Additional charging points for cars • Fleet control, optimization and dispatch software

Space cooling	7,500-15,000 INR/kW up front additional cost Ongoing cost of < 700 INR/kW-yr	• Smart AC controls • Control, optimization and dispatch software for connected cooling systems • Thermal energy storage systems • Smart monitoring and metering systems
Industry	Rs. 21,000 / kW upfront cost for FMS, system integrator and smart meters Ongoing costs are industry dependent ranging from the lower end for batch industries e.g. packaging and textile to very high for even partial; back down of process-based industries e.g. steel	• Control systems for isolating and shifting loads • Control, optimization and dispatch software for specific processes • Equipment R&M for sustaining flexible operation • Smart monitoring and metering systems

Source: CPI analysis

5.1.2 FLEXIBLE CAPACITY FROM AGRICULTURE PUMPING

Karnataka's agriculture sector accounts for a third of the total electricity consumption in Karnataka and contributes a fifth of the state's GDP. Most of this electricity is supplied either free of charge or highly subsidised to support farming.

Our analysis found that at the current rate of growth, the number of pumps used in Karnataka, for agriculture would rise by 50% over this decade, with a commensurate rise in the electricity consumption from agriculture pumps despite improvements in energy efficiency.

Table 5.2 Growth of agricultural pumping sets to 2030

	2017	**2030**
No of grid connected pump sets	2,630,765	3,863, 367
Energy consumed by pump sets (BU) *(5HP pumpset, running 4.36 hrs /day)*	20.1	29.5

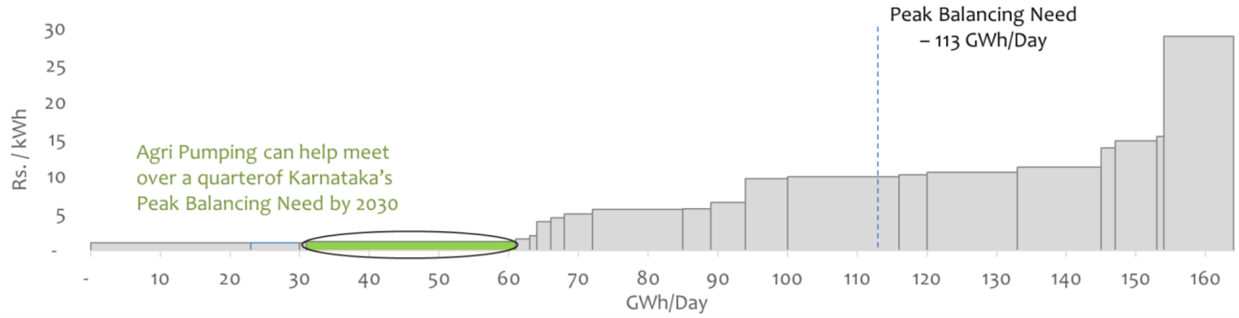
Source: SRPC annual Report, CPI Analysis

Agriculture pumping load is available in relatively long and reliable periods of flexibility, typically in blocks of 3 to 8 hours. This discrete block of energy consumption offers a highly adaptive source of flexibility. Supply for irrigation pumping does not necessarily need to be provided at any particular time of day and can be aligned closer to periods of generation peak to provide flexibility to the system.

Our analysis shows that by 2030, agriculture pumping could account for almost 30TWh of electricity consumption. Without any intervention and incentives, this demand is expected to be spread randomly across the day, with some of the load overlapping with periods of peak generation. Even if 25% of this load were shifted, Karnataka would benefit from c.30GWh of daily energy shifting potential which represents almost 27% of Karnataka's peak shifting needs in 2030 (figure 5.5).

Figure 5.5 Agriculture pumping could be a cost-effective way of meeting peak balancing in 2030

Peak balancing supply curve 2030

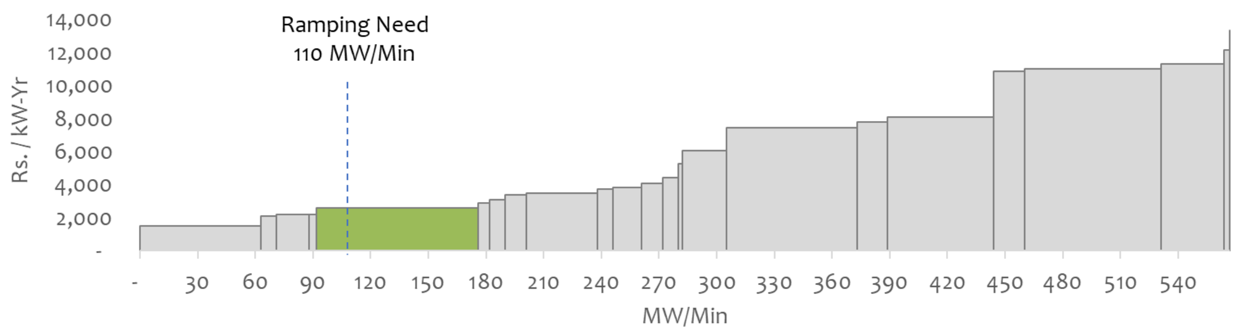


Source: CPI analysis

Agriculture pumping is also a marginal resource for ramping (figure 5.6) and could play a critical role in addressing Karnataka's growing ramping needs through the decade, along with its hydro capacity, as other resources such as EV charging and space cooling are still being developed.

Figure 5.6 Agriculture pumping could play a key role in meeting Karnataka ramping needs to 2030

Ramping supply curve 2030



Source: CPI analysis

While targeting flexibility from agriculture pumping, it is imperative that only the consumption of pumpsets is shifted, without any disruption to the supply to rural households and industries. To accomplish this, agriculture pumpsets should have a separate feeder which could be turned off during periods of high demand and turned on during periods of excess generation each day. In order to allow this freedom and to minimize T&D losses, a feeder segregation programme is currently underway that will:

- Increase revenues to the utility arising from loss reduction and/or change in sales mix in the project area;
- Shift load to off peak hours providing flexibility and also reducing the cost of peak power procurement;
- Improve quality of supply in non-agricultural segments.

A review of states that have successfully implemented the feeder separation programme reveals beneficial impacts in their ability to flatten their load curve, by shifting pumping demand to off-peak hours. For example, Gujarat, registered a growth of 10.39% in energy input, from 2007-08 to 2009-10, with peak demand only growing by 1.93%. Karnataka has already separated around 55% (table 5.3) of the state's irrigation pump feeders from domestic supply.

Table 5.3 Over half of Karnataka's agriculture supply is through dedicated feeders.

	IP* Connected to DAF**	IP* not Connected to DAF**	Agriculture feeders separated	Subsidy Claimed (Rs/kWh)
BESCOM	6,47,169	1,84,983	78%	2.81
HESCOM	2,44,219	4,06,277	38%	5.46
GESCOM	2,08,147	1,31,492	61%	5.05
CESC	2,39,953	98,729	71%	4.93
MESCOM	-	2,91,129	0%	4.76
HRECS	12,654	13,162	49%	4.65
Total	**13,52,142**	**11,25,772**	55%	4.4***

*Note: *IP = Irrigation Pumps; **DAF = Dedicated Agriculture Feeders, *** Weighted average subsidy across all state discoms*

Source: Dedicated feeder for IPs solar using solar based generation, 2019, CSTEP

While segregation of feeders helps capture the largest scope of flexibility from agricultural pumping, a programme to install solar-powered agricultural pump sets (KUSUM) represents an interesting alternative. Central government set a target of 20,000 pumps to be installed in the fiscal year 2019-20 and Karnataka is expected to participate in this programme, thus also boosting its deployment of distributed solar. Installation of off grid solar pumps would reduce the load from agriculture on the grid, but at the same time reduce the availability of agricultural pumping as a flexibility resource.

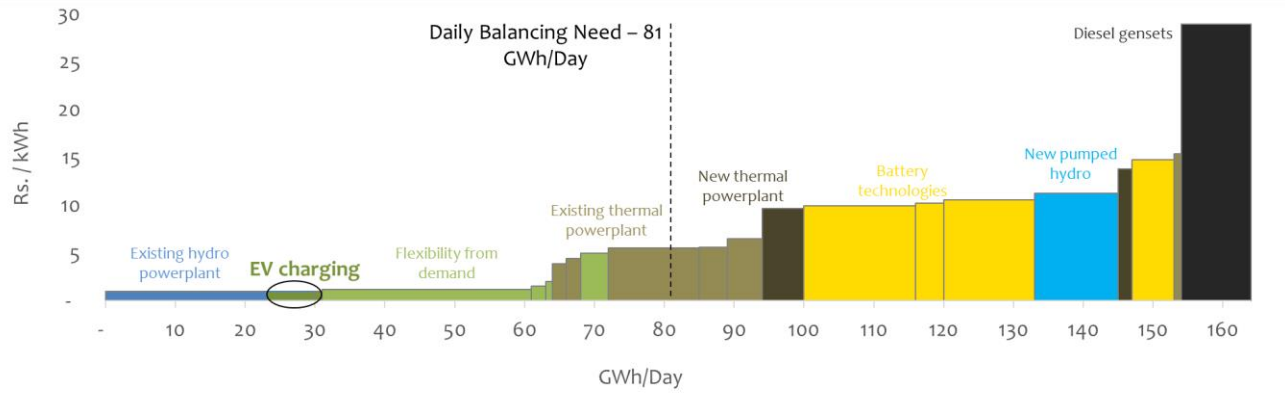
5.1.3 FLEXIBLE CAPACITY FROM EV CHARGING

EVs offer an attractive source of flexibility to the grid and despite the high cost of batteries which we will explore in the next section, this resource is worth pursuing for both its low-cost potential and the potential to smooth out evening peak demand. Without intervention, demand for charging EVs at the end of the day may intensify pressure on the grid.

Ideally EVs could be connected to allow two-way flow of electricity; charging when supply is plentiful and feeding back into the grid when supply is short. While this vehicle to grid (V2G) application is attractive, Karnataka, as elsewhere is many years away and will require infrastructure and inverters to allow the grid to dispatch and use energy, as well as sophisticated markets, metering and payment systems. However, even failing V2G, there are many attractive options to provide flexibility by shifting when batteries are charged.

Figure 5.7 EV charging could be one of the cheapest options for demand flexibility

Daily balancing supply curve 2030



Source: CPI analysis

Karnataka is at the forefront of India's transition to electric vehicles (EVs), being one of the first states to introduce policy for EVs along with storage. Karnataka's policy on EVs aims to support the sales boost in electric vehicles with setting up of charging infrastructure and special manufacturing zones. The state aims to achieve 100% electric mobility for auto rickshaws, cab aggregators, corporate fleets, school buses, and three/four-wheeler mini-goods vehicles by 2030[18].

To evaluate the market opportunity and barriers to EV flexibility, we have disaggregated the LDV market and usage by vehicle type and forecast growth and energy consumption to 2030 based on Karnataka's assumptions published in its 2017 EV policy publication, our discussions with vehicle manufacturer Mahindra and BNEF[19] which estimates 28% of fleet conversion to EVs for India by 2030.

We have conservatively assumed that a little over a quarter of all of Karnataka's vehicle fleet will be electric by 2030. We estimate 7GWh of daily energy shifting potential in Karnataka, in light duty vehicles (LDV) alone (figure 5.4) which represents almost 9% of Karnataka's peak balancing needs in 2030. Inclusion of busses and trucks could increase this potential substantially.

Table 5.4. EV electricity demand and consumption 2030

EV Segment	Vehicles ('000)		Demand (MW)		Energy (GWh/day)
	2019 (est)	2030 (est)	2019 (est)	2030 (est)	2030 (est)
Three Wheel (E2W)	26.7	2,524.2	166.6	15.776.1	5.5
Two Wheel (E3W)	1.1	177.9	6.8	1,111.9	0.3
Four Wheel (E4W)	1.5	187.5	27.9	3,516.4	1.4
Total	**29**	**1,237**	**201**	**20,404**	**7.3**

Source: Karnataka EV Policy 2017, BNEF, CPI Analysis

If the timing of charging the battery in the vehicle is adjusted across the day, charging could be economically attractive, as the cost of the battery is already paid for within the cost of the transport, so the additional expenses are incremental, e.g., connection, metering, and

[18] Karnataka, Electric vehicle and energy storage policy, 2017
[19] Electric Vehicle Outlook 2020, BloombergNEF

incentives. Increasing flexibility might require the installation of higher speed charging, but no new battery costs. Significantly, with the EV market just beginning to take off, there is an opportunity to influence the development of the EV market in ways that will increase the potential to use EVs to provide flexible resources. In this way, Karnataka may be able to simultaneously lower the cost of electricity supply while lowering the total cost of transport using electric vehicles.

The flexibility potential from EVs will largely depend upon the operational and behavioural characteristics of different vehicle segments, but also significantly influenced by the design of the charging infrastructure, which Karnataka can influence. Without intervention, it is possible or likely that EVs across all the vehicle categories will be plugged in at the end of the day, adding to the evening peak demand and ramping requirements. Provision of flexibility depends critically on the system used for charging. We explored two options for delivering flexibility:

- **Battery in vehicle charging**, where the battery is fixed in the vehicle and the entire vehicle is stationary during charging.
- **Battery swapping charging**, where depleted batteries are swapped for fully charged batteries when needed.

Battery in vehicle charging. With battery in vehicle charging, we see two options to provide a degree of flexibility. The least expensive is to provide incentives to delay the charging of the vehicle beyond the peak demand and ramping period in the evening until after midnight. This method requires timers to delay charging and monitoring, meters and incentives to enforce and incentivize the delay. Since E2W and E3W batteries are relatively small, at an average of 5kWh or lower, they can be charged fully in a few hours, so the delay will not require installation of fast chargers. However, this method only avoids adding more ramping and evening peak demand to the grid but does not contribute positively to reducing the need for daily shifting nor provide short or long-term reserves.

Given the growth and economic attractiveness of solar PV generation, our flexibility needs analysis showed that daily shifting demands require moving evening and night-time consumption to the day. As E2W vehicles will be used for morning and evening commute and sporadically throughout the day, charging during the peak generation hours maybe possible if sufficient chargers are installed around corporate and commercial buildings but these might still be limited as compared to demand if batteries take several hours to charge. E3W vehicles will primarily be used during the day and charging during the peak generation hours may coincide with usage and would likely interfere with revenue generation from fares for the E3W owners. Since the batteries will take several hours to charge at normal levels, shifting charging to the day becomes realistic only with the installation of fast chargers. These fast chargers would need to be shared among many operators and have pricing incentives or timing restrictions to create the energy shifting.

We estimate that large-scale installation of fast chargers could shift 950MW of evening peak and create 3.8GWh/day of daily load shifting, between 20-25% of the EV potential. This method of shifting is likely to cost between Rs. 2 - 3/kWh, factoring in the capital costs of the chargers and the incentive and billing systems required.

Battery swapping: The alternative to charging batteries while the EVs are in use is to replace a depleted battery with a fully charged one. The smaller battery size and vehicle design makes this process straightforward for E2Ws and E3Ws. In fact, this process is already in use with lead acid batteries. This option may be more conducive to E3Ws where there is greater standardization than E2Ws where customers maybe hesitant and where less standardization and more variations are expected across different manufacturers.

With the battery no longer connected during the charging period, usage constraints of the vehicle itself no longer need to drive timing and speed of battery charging. Furthermore, battery swapping enables greater aggregation of charging, either for amortization of the costs of fast chargers, or consolidation of metering, billing and incentive mechanisms. In fact, one option would be for the utility, to run these battery charging businesses themselves to enable complete control over charging timing and speed and thus allow the charging load for daily shifting, reserve, the smoothing of ramping, and locational balancing. Even without direct utility involvement, incentives can provide access to greater flexibility that will reduce the costs of both electricity and system operation.

Two options for providing flexibility from battery swapping include slow charging batteries during peak solar generation hours for use the next day, or operation of fast chargers that will allow reuse of batteries within an hour. There is likely to be greater flexibility benefits in the slow charging of batteries, as this will give the utility an option to follow load across the day, although the fast chargers will help shifting and could provide some of the other flexibility services. The cost differential between the two methods will depend upon the relative cost of fast chargers and batteries, as the slow charging method will require that rechargers maintain a significant inventory of batteries. A combination of the two methods is likely to provide even more flexibility benefits. The precise business case needs further investigation, as will the market requirements and energy and ancillary service contract requirements required to incentivize and access the flexibility.

Our estimates indicate that with universal roll out of the battery swapping model, Karnataka could access 80-100% of the EV flexibility potential, roughly six times that of the battery-in-vehicle model.

5.1.4 FLEXIBLE CAPACITY FROM SPACE COOLING

Karnataka's space cooling market has a large potential, driven by the growth of business parks and special economic zones, especially in and around Bengaluru, its capital city and one of India's largest hubs for IT and data servers, a sector with large electricity demand.

On the residential cooling side, Karnataka is starting with a very low penetration (~4%[20]) but with growth expectations in line with India, which expects to see 70% AC penetration by 2040, driven by more frequent cooling degree days and greater affordability thanks to increases in household income.

Shifting the time of use for the air conditioning by a few minutes or hours, or precooling using thermal energy storage for Central ACs adds 'within the day' balancing capacity for grid management. Increasing the thermostat temperatures by even 1 degree reduces the cooling load on the system, easing grid balancing, especially during peak demand.

RESIDENTIAL AIR CONDITIONING

Our research showed that room ACs account for only 30% of all cooling load in Karnataka, and this demand is expected to increase to c.42% over the decade to 2030.

Currently there are around 800,000 room air conditioners in Karnataka, which is a very low level of penetration compared with states like Tamil Nadu[1]. Annual additions of 200,000 over the next decade will bring Karnataka's total figure to 3.2 million residential units.

Meanwhile, efficiency of air conditioners is improving, and electricity consumption by an average air conditioner is expected to halve by 2030. Factoring in this energy efficiency benefit, the load from room ACs is expected to almost quadruple by 2030.

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[20] Motilal Oswal, 2018 - https://www.motilaloswal.com/site/rreports/636692290896064596.pdf

Table 5.5 Potential for flexibility from residential air conditioning projections

No of room air conditioners as of 2017	789,617
Expected growth rate	11.5%
Expected no of room air conditioners by 2030	3,263,752
Power consumption p.a. for a 1.5ton AC (approx.) (kWh)	1096.6
Connected load (GW) - 2030	4.7
Flexibility potential as % of total connected load (GW)	10-25%

Source: Motilal Oswal, 2018, CPI analysis

If this load can be harnessed for flexibility, it would add to the relatively low-cost flexibility potential from demand for Karnataka. For our analysis, we have considered a conservative 10-25% of the total as capacity that participates in providing flexibility services.

To tap into the flexibility potential of the residential cooling load, consumers either need to be directly contracted or incentivized to turn their ACs down when needed by the grid and system balancing services or need to be connected to smart systems with automated controls which could temporarily reduce their electricity consumption, on pre-agreed parameters, during peak times. Smart air conditioners which can connect to home automation devices have been launched in the Indian market, but currently these are not the most energy efficient and can cost up to 50% more than the existing options. Smart plugs are also available at an average price of ~Rs 4,000 per plug which can be used with non-smart ACs for switching the devices on/off remotely through mobile apps based on DR signals. This can integrate large volumes of the room AC load for flexibility.

COMMERCIAL (CENTRAL) AIR CONDITIONING

Our research shows that total installed capacity of central air conditioners in India is currently 33 million tons. With rapid urbanisation, central air conditioning capacity is expected to grow at a CAGR of 11% to reach an installed capacity of 122 million tons by 2030[21].

The connected load from central ACs in Karnataka is expected to more than double by 2030 from 3.3GW to 7GW. Central air conditioning load alone would represent around 30% of the state's peak load of 22 GW. Bengaluru is often referred to as India's Silicon Valley as it is home to more than 70,000 IT companies. Office complexes and data centers are expected to be the largest consumers of central air conditioning capacity.

Central air conditioners can help provide flexibility by reducing the cooling load for a short duration during peak demand or by using precooled thermal energy storage systems which allow the cooling systems to be switched off during high demand/peak periods. It is easier to implement flexibility options such as thermal storage with central ACs as a substantial load is controlled from one point.

Our analysis also revealed that although there is a high cost of retrofitting thermal storage systems in an existing central cooling system, the cost of greenfield installation of a cooling system with thermal storage is the same as a conventional central cooling system. This is achieved through dual use of the chilling equipment under sizing of the chillers themselves

[21] Research and Markets - https://www.researchandmarkets.com/r/sv8sbt

because they no longer need to be designed for peak cooling need as the peak can be served through the thermal storage.

5.1.5 FLEXIBLE CAPACITY FROM INDUSTRY

Industry accounts for 18-19% of the total electricity demand in Karnataka[22]. Industrial demand is composed of diverse sectors with some energy intensive industries processes running round the clock (e.g., iron & steel; chemical) while others with more variable load (e.g., cement, sugar, textile). The cost vs. value of shifting energy consumption across the day or year changes depending on the economic case for adjusting production schedules or additional investment to allow product storage or shift the timing of energy intensive processes. However, these options will never be found or implemented if the value of the shifting is unknown and if there are not market signals or contracts that incentivize industrial consumers to make investments or shift schedules.

The iron & steel industry represents about 42% of the total industrial demand, while cement and chemicals represent around 10% of the industrial demand in Karnataka[23]. Estimates suggest that, depending on the industry, between 5%-14% of a consumer's demand would be available for load shifting

One sector that is on the higher end of the flexibility estimate is textile, offering up to 25% load shifting capabilities. Karnataka is the second largest hub of unorganized textile and receives direct support from the state government to motivate continued growth of this sector. Tied to the incentives for the sector, additional push by the government to structure and align electricity access and consumption with the peak generation periods and participation in incentive-based load shifting programmes can create the dual benefit of reducing overall costs for these textile manufacturers as well as contributing to peak reduction and grid management.

A full understanding of the flexibility potential of industry in Karnataka will require in depth discussions and analysis with representative companies across a number of sectors. The importance of industrial flexibility within the context of system management and balancing should make the inclusion of industry voices and analysis an important step in designing electricity markets.

INDUSTRIAL FLEXIBILITY FROM CAPTIVE GENERATION

Table 5.6 Industries in Karnataka (>1MW) by electricity demand and their captive capacity

	Iron & Steel	Cement	Mineral O&P	Chemical	Sugar	Others	Total
Demand (GWh)	7,387	1,947	1,154	1,013	1,242	7,977	20,720
Self-consumption (GWh)	7,613	2,034	1,196	593	2,327	1,201	14,964
Captive capacity (MW)	1,369	622	242	219	1,136	1,823	5,411

Source: India Electricity Statistics (General Review), CEA, 2019

[22] Annual Report, SRPC, 2018-19
[23] India Electricity Statistics (General Review), CEA, 2019

For industrial consumers with over 1MW load, over half of the demand is met through self-generation, with captive capacity of c.5.4GW (table 5.4). Out of the total energy generated through captive generators, 90% of the energy is used by the generator, and the remaining is exported back to the grid. Almost 80% of this self-generation uses coal and gas, with the rest is met through diesel generation and some renewable energy on the margins. Even a fraction of the captive capacity could play an important role in managing Karnataka's daily shifting needs.

Current arrangements allow captive generators to sell excess energy to the utility up to a maximum of 10% of their net generation. We understand that the pricing of these exports do not reflect the value of the energy to the discoms, but instead are based on comparative cost estimates of energy production. Fixing energy markets to provide better price signals to incentivise captive generation to make more of a contribution to flexibility services could be a major near-term improvement to the efficiency of the system, and an opening to the development of fuller functioning markets.

Captive generators already use metering to measure input and exports to the grid, with commercial arrangements in place to pay for energy production, and the ability to respond to the grid by changing the output of the captive powerplants. However, more responsive value-based pricing would encourage industrial consumers with captive generation to make decisions on the following:

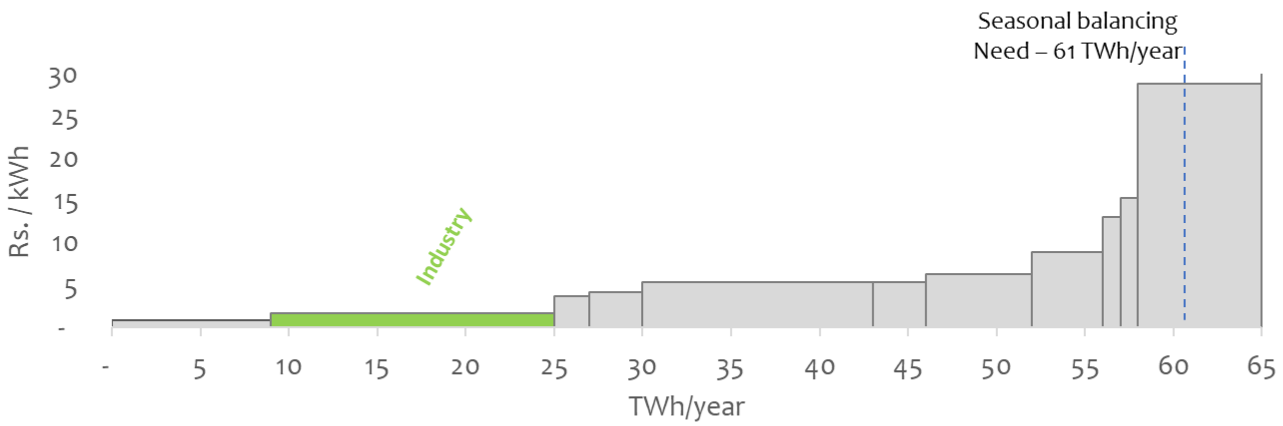
1. When to generate or buy from the grid, which may be more attractive in hours of excess wind or solar production;
2. When to generate excess electricity and export it when the grid is short of supply;
3. Whether to shift production or energy use to facilitate more export when grid prices are attractive and more consumption from the grid when there is excess energy on the grid.

Crucially, the last point implies that with the right incentives, industrial players with captive generation will easily be able to extend their delivery of flexibility from their captive plant ownership to their entire system. Since over half of industrial load in Karnataka is driven by consumers with captive generation, the implication is that relatively straightforward adjustments to captive generation pricing, whether improved time of day pricing or full-scale locational marginal pricing, would open up access to over 50% of all industrial demand and improve the flexibility of the captive generation itself.

SEASONAL INDUSTRIAL FLEXIBILITY

Figure 5.8 Flexibility from industry can help Karnataka meet Karnataka's seasonal shifting needs at low cost

Seasonal balancing supply curve 2030



Source: CPI analysis

Industry also has the potential to participate in meeting Karnataka's seasonal shifting needs, especially in the medium term as Karnataka continues to add wind capacity to its portfolio.

Our analysis indicates that one of the cheapest sources of seasonal flexibility is to develop incentives for industrial consumers to time their lower consumption months with period of lower renewable energy output (figure 5.8). In addition, incentives to time maintenance of captive generation, or otherwise reduce output during high generation months, could be an important first step in managing seasonal balancing.

Industrial consumers will need price signals and/or contractual arrangements to incentivize these shifts. Individual case studies of captive generation assets and the assessment of the potential in this market are crucial next steps in developing a long-term perspective on seasonal flexibility from this source.

5.1.6 BARRIERS TO FLEXIBILITY FROM DEMAND

If designed well and introduced at the appropriate time, demand flexibility could be the single most valuable resource in a modern, flexible and affordable clean energy system. However, our current electricity systems are built around providing supply flexibility for many decades. Adding flexibility from demand will require developing new systems, measurements, monitoring and relationships that take time to develop. It will also require overcoming barriers, many of which have developed as consumers adopted o the way electricity has been traditionally supplied.

Some of these barriers are physical. Inadequate building stock insulation makes it difficult to shift the timing of cooling, for instance. Measurement provides more barriers. To provide effective demand response, we need to understand the energy consumption pattern for a particular end use and observe how that pattern changes with incentives. In cases like agricultural pumping, efficient demand response will require separate metering along with the completion of the supply feeder separation. Behaviour provides further barriers. To recruit consumers into shifting and changing how and when they consume electricity, we need to demonstrate benefits and savings that these changes can bring to the consumers. Overall, development will take time and move in stages as technology, incentives and business models improve and develop in response to the demand flexibility levels delivered.

5.1.7 MARKET REFORM TO INTEGRATE FLEXIBILITY FROM DEMAND

In many ways, the investments in infrastructure and policy interventions required to develop demand flexibility are the most complex. But if designed well and introduced at the appropriate time, demand flexibility could be the single most valuable resource in a modern, flexible and affordable clean energy system.

As with other aspects of market reform, data is at the heart of its development and most efficient and economically effective deployment.

Karnataka has a great potential to expand the flexibility from demand, from just over 10GW today to 20GW, and maybe even 31GW by 2030. Most of that flexibility from demand can be developed as a very low-cost resource. But in order to achieve that tripling of low-cost flexibility from demand, the state will need to tap into primary sources of flexibility available today such agricultural pumping, space cooling and industry as well as put in place the necessary interventions to encourage newer resources such as EV charging as a future significant source of flexibility.

If Karnataka starts to address some of the barriers to scaling up flexibility from demand now, the outcomes from those actions today will have maximum impact in the future. The main areas that the state policymakers and discoms could address to overcome barriers:

- End-use data must be collected, rather than the focus today on supply data, which will require investment in smart infrastructure and equipment
- Utilities, aggregators and industry should collaborate to explore ‘quick wins’ such as pre-defined tariff arrangements
- Targeted procurement of flexibility from demand, especially from industry and commercial consumers, to both set parameters for customers and assure consumers of recovery of cost of any upfront capex on smart systems and metering. It will also allow the discoms to better forecast their supply before systems and practices mature
- Contracts should be tailored for these new demand flexibility services, with platforms created for sharing data and generating price signals from demand
- Pricing mechanisms should include time of day or time of use incentives for residential and commercial users.
- Update scheduling, monitoring, and metering systems to accommodate customers as the new suppliers, new services and new tariff structures
- Capacity building at the utilities and consumer education through multiple channels including recruitment of influencers to target behavioural barriers
- Pilot programmes will also be a useful source of learning by doing as the structure of flexibility from demand is built out in Karnataka.

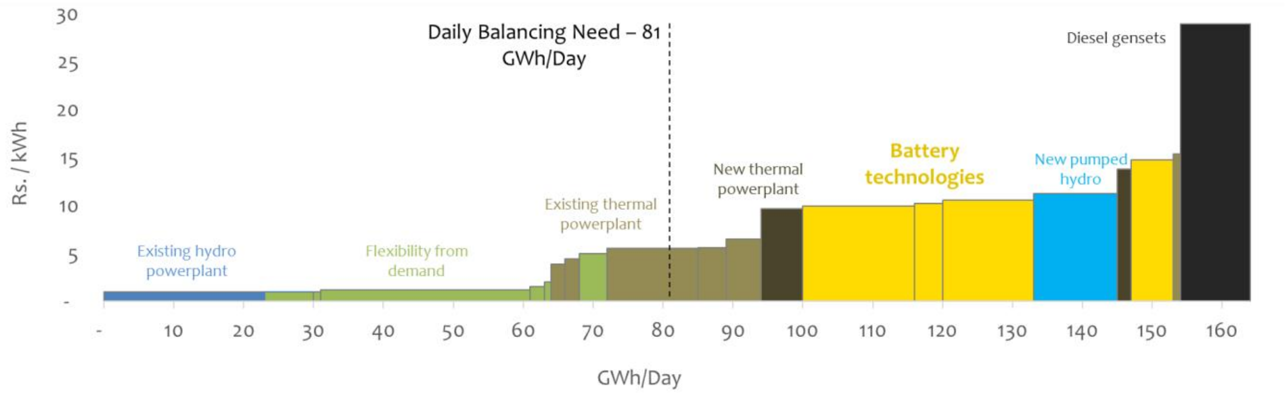
5.2 Meeting Karnataka's flexibility needs using storage technologies

Energy storage has significant potential in integrating and balancing Karnataka's electricity system, as share of variable renewable increases in the state generation mix and the pipeline of powerplant projects remains uncertain while some of the older powerplant units are scheduled for retirement. For a state like Karnataka where solar generation dominates, adding battery storage could provide a valuable fast response resource to manage the variable, yet relatively predictable, supply. Increased storage deployment can reduce grid imbalances by reducing the steepness of the duck curve as shown in figure 4.9 in the section above. Despite the good match between solar and batteries, over-reliance on batteries for storage may add significantly to the overall system cost, at least some of which could have been avoided, by development of other resources for flexibility, like demand.

Our analysis shows how storage, battery as well as new pumped hydro are amongst the more expensive flexibility resources to meet the daily balancing needs for Karnataka (figure 5.9).

Figure 5.9 Storage would still be among the more expensive options to meet daily balancing needs by 2030

Daily balancing supply curve 2030



Source: CPI analysis

To be cost competitive, a battery storage setup needs to meet multiple needs – for instance the same battery unit serving distribution system balancing and wholesale market ramping. However, markets in India and elsewhere are not yet developed enough to deliver these multiple flexibility needs from one unit efficiently. If the capital cost of a battery can be paid by reducing the need to build transmission or distribution infrastructure, for example then batteries can be used to perform daily balancing.

The key for Karnataka thus is to view the development of energy storage in context of its future flexibility needs and what technologies fit where. Market signals created will then need to align with these needs. Effectiveness of incentives and direct investments could be increased if aligned with other state programmes that encourage their uptake. For example, battery storage will be essential in helping the state meet its electric vehicle ambitions and could have additional benefits if they can be located where needed to reduce transmission and distribution constraints and balance the grid.

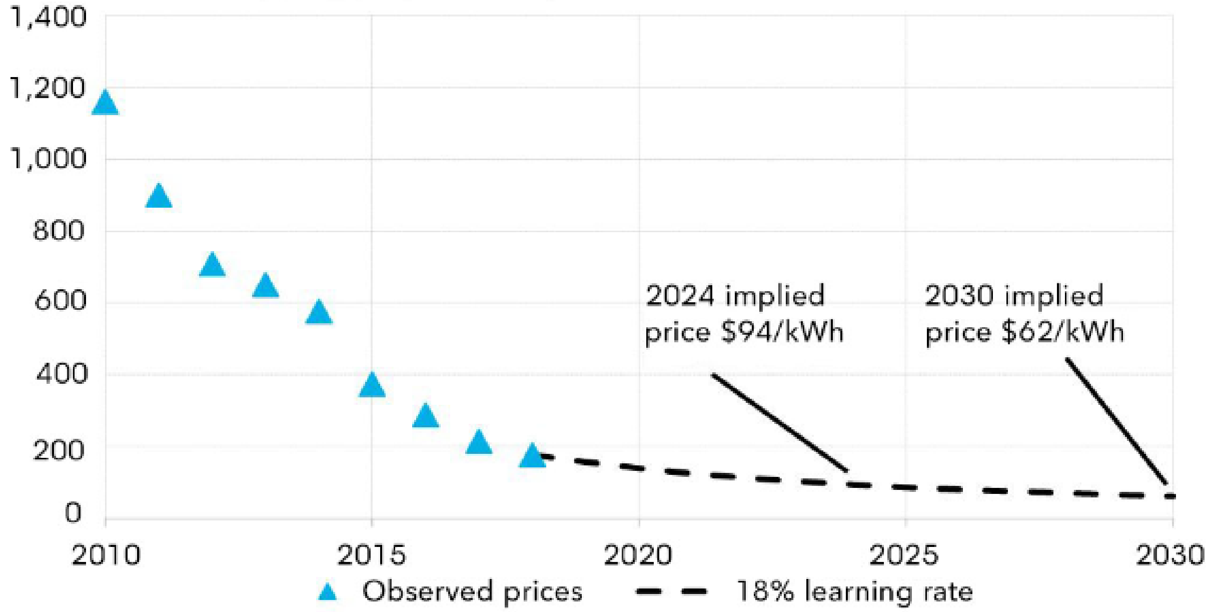
However, optimizing location of batteries, use of batteries in multiple services such as ramping, daily balancing, and reserves, and incentives to develop, install, and dispatch storage all require significant improvements in India electricity markets. These are the same improvements that are needed to access greater flexibility from existing thermal powerplants in the transition and in developing and rolling out demand side measures. Thus, even if batteries were the only solution, working with powerplants and demand is essential to develop appropriate markets.

5.2.1 COST OF STORAGE

Battery storage costs have declined sharply over the years, a trend that mirrors part of the journey that solar and wind generation technologies have seen to reach their current low prices and large-scale affordability. Storage technologies such as flow batteries, power to hydrogen, sodium sulphur or something new may eventually emerge as cost effective options for grid storage, but lithium-ion battery costs continue to decline dramatically. The intense price competition, driven by global-high volume manufacturing to supply the electric vehicle (EV) market is forcing manufacturers to develop new chemistries and impove processes to reduce production costs.

BNEF[24] projects the annual demand for lithium-ion batteries is expected to pass 2,000GWh per year, with EVs accounting for 85% of the market. Battery pack cost decline trajectories are expected to further steepen from previous estimates, shaving off two-thirds from 2018 levels to land around US$62/kWh by 2030 (figure 5.10).

Figure 5.10 Lithium-ion battery pack costs (US$/kWh – Real 2018)

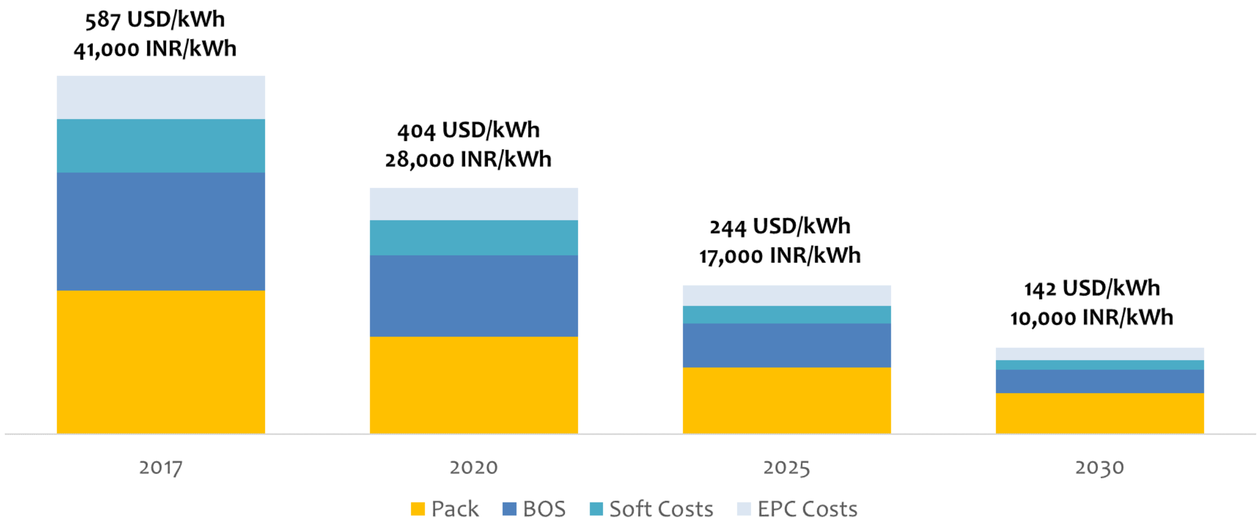


Source: BloombergNEF

Balance of system costs and soft costs for engineering, production and construction (EPC) currently make up as much as 70% of the total system cost. But these costs are expected to halve to 2030, with the benefit of learning by doing. We expect battery energy storage system (BESS), using lithium-ion batteries in India will see almost three-quarters of drop from their current prices, to c.INR 10,000/kWh (figure 5.11)

24 BNEF 2019 Battery price survey - https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/

Figure 5.11 Battery energy storage systems – installed system costs for India (US$/kWh)



Source: Based on McKinsey figures, assuming India BOS discount of 25% by 2030, increasing from no discount in 2017. 2030 extended based on 2017-2025 CAGR. Exchange rate - 70 INR/USD.

STACKING OF SERVICES, COMBING VALUE STREAMS

Even with the projected reduction in costs, battery storage remains a costly resource compared with other resources for flexibility, such as demand and powerplants, especially when it is setup to exclusively meet specific flexibility needs. Flexibility needs that occur on a relatively frequent basis, for example shifting a load for four to eight hours a day, every day, from when the sun shines to nighttime, is economic because the capital costs can be amortised over many hours and 365 cycles. Infrequent cycles that shift energy across the week or even between seasons would not be an economic application for batteries. If the capital cost of a battery can be paid for by reducing the need to build or extend transmission or distribution substations, or when the same battery technology is put to multiple applications, i.e. 'stacking' battery storage services, the battery storage can be more economic. For example, batteries can manage evening ramps, smooth electricity prices through arbitrage, provide black start capability, mitigating risk of curtailment, and back-up power.

STACKING, INTERNATIONAL EXPERIENCE

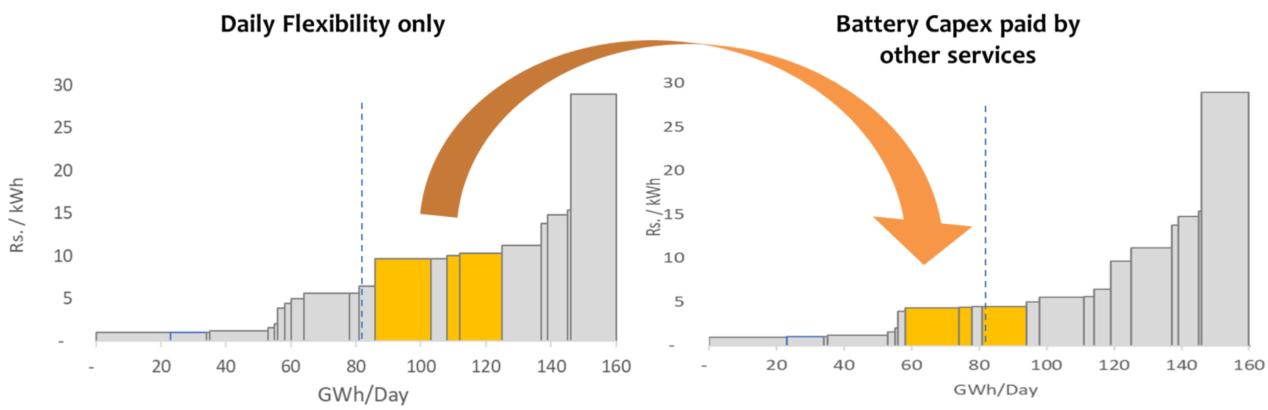
In Figure 5.12, a review of storage projects in the US reveals that most projects already combine value streams. There are many possible ways to combine applications. However, some applications are better suited for stacking such as combining energy shifting with bulk system support or voltage support, voltage support utilisation for reserve capacity with energy shifting, T&D deferral capacity for voltage support or capacity deployed for 'time of use' energy cost management for maintaining electric service reliability and quality. There are some applications of battery energy storage that have low compatibility with other services such as wind integration, area regulation and reliability services.

Figure 5.12 Many storage projects already combine value streams

IMPACT OF STACKING ON COMPETITIVENESS OF BATTERY STORAGE AS A FLEXIBILITY RESOURCE

When stacking multiple applications from a battery storage system, capital costs can be reduced considerably by amortization across different services, reducing the reducing the respective cost of providing each of the services (figure 5.13). In this example, batteries used only for daily balancing, as on the left-hand side will continue to be too expensive to compete with other flexibility resources in 2030, however when this battery system is applied across multiple services, storage resources become marginal for daily flexibility needs.

Figure 5.13 stacking can make battery storage more competitive



Source: CPI analysis

5.2.2 DIFFERENT BUSINESS MODELS CAN CONTRIBUTE TO MEETING FLEXIBILITY NEEDS

Battery energy storage is modular, highly scalable, and can be used at any point in the electricity grid – at the consumer end, on the distribution system, or in the bulk system. Depending on where they are located and how they are integrated into the system, battery systems are uniquely suited to meet different flexibility needs (figure 5.14).

Different business models include:

- **Substation/ Wholesale**. KPTCL, KPCL or an IPS[25] owns and operates battery storage capacity at distribution nodes and transmission hubs to meet grid balancing and system flexibility need, and reduce/ delay addition of new T&D infrastructure
- **Behind-the-meter (BTM)**. Back-up storage capacity owned and operated by industry (large scale) or households and small commercials (small scale)
- Adding energy service providers who can **aggregate** BTM storage capacity through contracts, for consolidated storage capacity to trade with utility
- **Energy service company (ESCO)**. ESCO owns and operates storage capacity, with KPTCL or KPCL managing the grid interface
- **Co-located with renewable generation**. Owned and operated by renewable generator to smooth intermittent supply at utility scale, and intermittent access for distributed capacity

Figure 5.14 Different models can target different flexibility needs and integration of battery storage at different points in the electricity system

	Short Term Reserves	Ramping	Daily Balancing	Peak Shifting	Seasonal Shifting	Trans. Deferral	Dist. Deferral
Substation/ Wholesale	✓✓	✓✓	✓✓	✓✓		✓✓	✓✓
Behind the Meter -Small Scale	✓✓		✓✓	✓✓			✓✓
Behind the Meter -Large Scale	✓✓	✓	✓✓	✓✓	✓	✓	✓
System Aggregator	✓✓	✓✓	✓✓	✓✓		✓	✓✓
ESCO	✓✓	✓✓	✓✓	✓✓		✓	✓✓
Co-located with RE – Rooftop/ Agriculture		✓	✓✓	✓		✓	✓✓
Co-located with RE – Utility scale	✓✓	✓✓	✓✓	✓✓		✓	✓✓

✓✓ Strong technical fit ✓ Potential technical fit Primary Design Objective Secondary Design Objective

5.2.3 BARRIERS TO FLEXIBILITY FROM ENERGY STORAGE

Battery storage faces a number of market and policy barriers:

- **Value discovery**. The value of energy storage can be very location-specific and time-dependent, but electricity pricing is not nearly granular enough to reveal the value of storage at different points of the grid at defined time intervals. The characterization and

[25] Independent power storage, with similar model in the battery storage sector as IPPs in the generation sector.

cost of distribution grid constraints are also very opaque, making it difficult to show where energy storage may have value in avoiding distribution grid upgrades, and stacking this value with energy shifting and grid services values.

- **High costs**. Storage can be targeted through multiple technologies and chemistries, all of which are at different stages of evolution – Lithium-ion, NaS, VRF, H2 storage and some that are more niche such as flywheel capacitors, etc. Battery energy storage backed by lithium ion is the most evolved out of these options, largely due to the demand from electric vehicles and the prices are declining fast, but the technology and its deployment is still expensive and business models that can fully extract value and deliver favourable project economics are limited.
- **Market size**. Energy storage, especially battery energy storage is at the start of its journey in electricity system deployment and hence the market suffers from lack of long-term visibility into the needs of the utility and market going forward. There is also difficulty in recognising the size of the market especially in use cases like T&D deferral.
- **Immature value chain**. The grid energy storage industry in India is nascent and underdeveloped. Project developers and system integrators are undercapitalized, and standards / expectations for project quality have yet to emerge. The industry will need to mature significantly to be capable of deploying energy storage at scale and attract sufficient financing.
- **Awareness gap**. Driven by the demand from EVs, battery storage has captured business and consumer minds alike however it is largely perceived as a resource to either provide expensive back-up, make renewable generation dispatchable by locating battery storage with wind or solar projects or power EVs. Awareness and capacity building is required across utilities, suppliers, manufacturers, service providers and consumers to fully capture the possibilities of battery storage within the modern electricity and transport system
- **Policy hurdles**: CERC recently upgraded the LTOA and MTOA Connectivity Regulation, that would now allow battery storage to sell energy back to the grid and the market, a prerogative otherwise limited to generators[26]. The recently updated Real-time markets and Ancillary Services market regulations have started to pull together a marketplace for the sale and purchase of some trading services, but there is some way to go before the market mechanisms can be utilised for price discovery from all resources.

5.2.4 MARKET REFORM TO INTEGRATE ENERGY STORAGE

Investments in battery storage systems, especially at any considerable scale are unlikely to materialise in the absence of regulatory and value signals. Battery storage has an important role in Karnataka's electricity system, for management of within day imbalances between solar generation and evening peaks, increasing electrification and expensive and low-reliability coal-fired generation and finally fast response to ramping and grid balancing requirements. Batteries can also provide a cheap source of demand flexibility, thereby making a case for the development of a domestic supply chain and a state-based battery manufacturing industry.

In Box 1, on the next page, we share the approaches adopted by other electricity systems internationally, solutions that have supported these systems in adopting and integrating storage technologies to various degrees, and have been considered when arriving at the

[26] CERC Grant of Connectivity Regulation (Seventh amendment) 2019 - http://www.cercind.gov.in/2019/regulation/Gazette%20Connectivity%20Regulations%20(7th%20Amendment).pdf

recommendations for Karnataka. Policymakers in Karnataka should focus on the following to overcome the hurdles for adoption of battery storage in Karnataka:

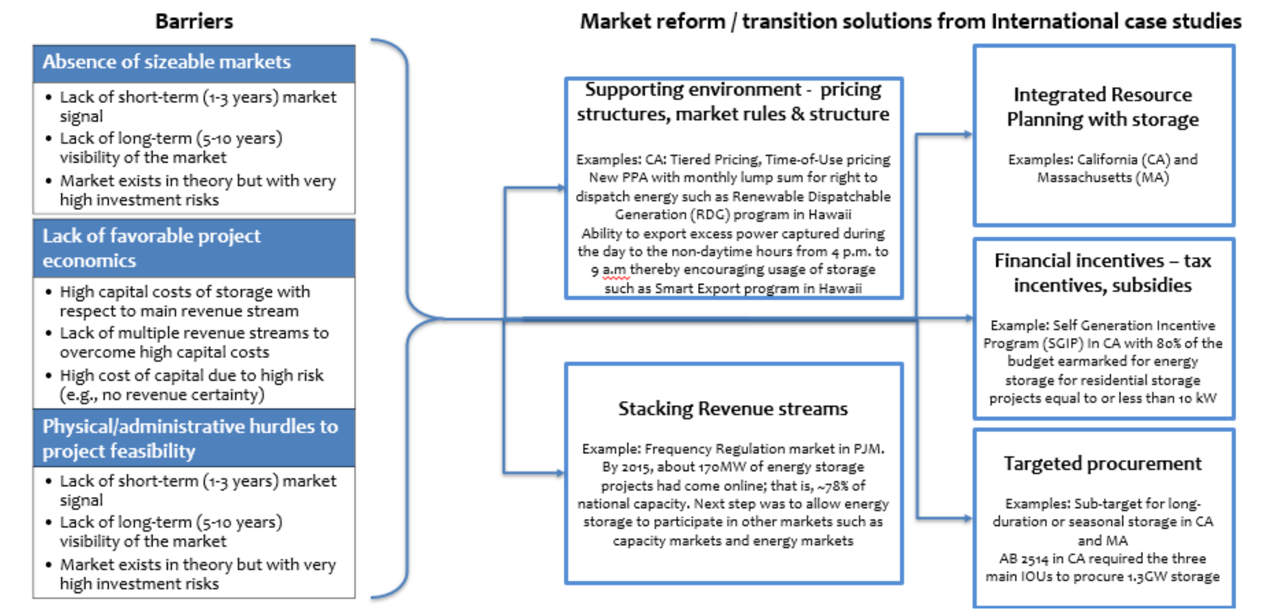
- The Karnataka Electricity Commission could amend the Karnataka Electricity Grid Code to recognise batteries as a grid entity so that the technology can be used to withdraw and inject power from/into the grid.
- Identify the nodal points on the distribution and transmission network by analysing the feeder level load pattern for deployment of grid level battery storage.
- Guidelines on battery storage contracts should include long-term revenue streams and allow it to participate in multiple services to manage system imbalances and frequency regulation even if there is no market today. Otherwise, the high cost of storage will be passed through to consumers.
- Provide long-term regulatory and policy certainty by amending the regulations to encourage investments in the battery supply chain that will further reduce the cost.
- Targeted tariff structures to support different business models, e.g. behind the meter storage, grid level deployment, co-located with renewable generation, etc
- Temporary market carve-outs for storage to participate in fast frequency response and broader ancillary services

Box 1: International case studies for energy storage incentives

Our analysis of international markets suggests policymakers through a combination of tools and mechanisms to target and incentivise development and storage.

Step 1	Integrated Resource Planning identifying flexibility needs	Example – California and Massachusetts
Step 2	Targeted Procurement for specific applications and services	Examples: • AB 2514 in California required the three main IOUs to procure 1.3GW storage • Sub-target for long-duration or seasonal storage in California and Massachusetts
Step 3	Incentives, such as tax and subsidies	Example: • Self-Generation Incentive Program (SGIP) in California with 80% budget earmarked for storage
Step 4	Supporting environment – pricing structures, market rules and structure	Examples: • Tiered Pricing, Time-of-Use pricing in California • New PPAs with monthly 'lump sum payments' for right to dispatch energy such as Renewable Dispatchable Generation (RDG) program in Hawaii • Ability to export excess power from daytime to the non-daytime hours (4pm to 9am), encouraging storage use such as Smart Export program in Hawaii

Step 5	Create new regulation market structure/ environment – Multiple Revenue streams	Example:
		• Frequency Regulation market in PJM
		  • market-based compensation to resources that have the ability to adjust output or consumption in response to an automated signal
		  • By 2015, about 170MW of energy storage projects had come online, c.78% of national capacity
		  • However, with the lack of multiple revenue streams and high costs, the learning was to allow energy storage to participate in other markets such as capacity markets and energy markets



5.3 Meeting Karnataka's flexibility needs from powerplants

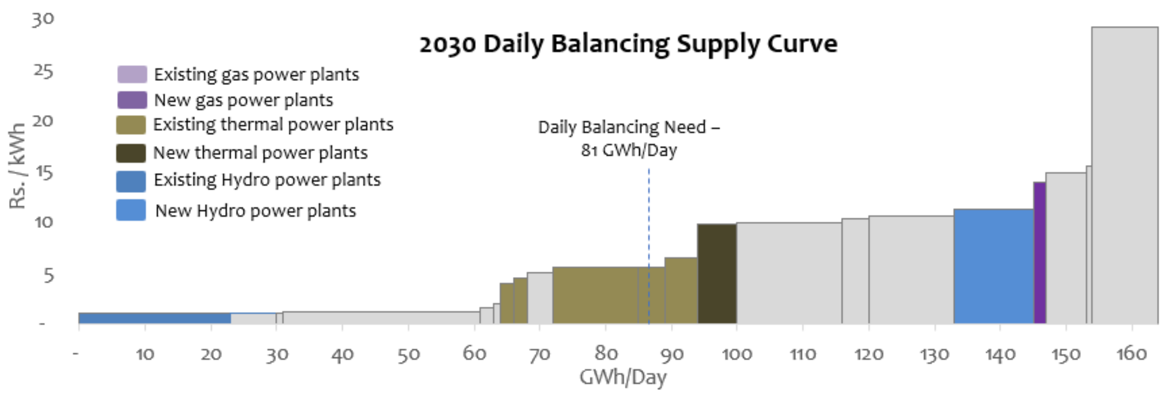
Powerplants in Karnataka make up over half of the current installed capacity for the state and have a significant role in meeting the state's flexibility needs. Out of the current 25GW installed capacity in the state, hydro and thermal make up 15% and 37% respectively.

Abundant hydro resources (3.8GW) in the state are primary sources of flexibility in the current electricity system, being deployed primarily to meet daily shifting and ramping needs. Reservoir-based hydro power plants are well-suited to meet both scheduled and unscheduled variations in residual load due to their high ramp rates and low start-up and shut-down times. However, the must-run status of hydro during the monsoon limits its flexible dispatch and seasonal balancing capacity.

Thermal generation, all coal in case of Karnataka accounts for 56% of the total electricity generation in the state[27], but the average annual plant load factor dropped from 73% in 2015-16 to 31% in 2018-19[28]. Without domestic resources of its own, these PLF declines are mainly driven by dependence on coal from other states which incur high costs for transport over long distances, high costs of international coal imports and the increasing availability of much cheaper renewable generation capacity.

Thermal powerplants have an important role in expanding Karnataka's range of flexibility options in a portfolio that blends this resource with demand flexibility and energy storage, The plants low PLFs can be strategically deployed to deliver maximum impact for the state's electricity system, especially as Karnataka targets higher renewable capacity to 2030. Our analysis, figure 5.15 shows that both hydro and thermal generation will offer some of the most cost-effective sources of daily flexibility in 2030.

Figure 5.15 Karnataka's hydro and coal plants are expected to offer some of the cheapest sources of daily flexibility by 2030



Source: CPI analysis

5.3.1 HYDRO POWERPLANTS AND FLEXIBILITY

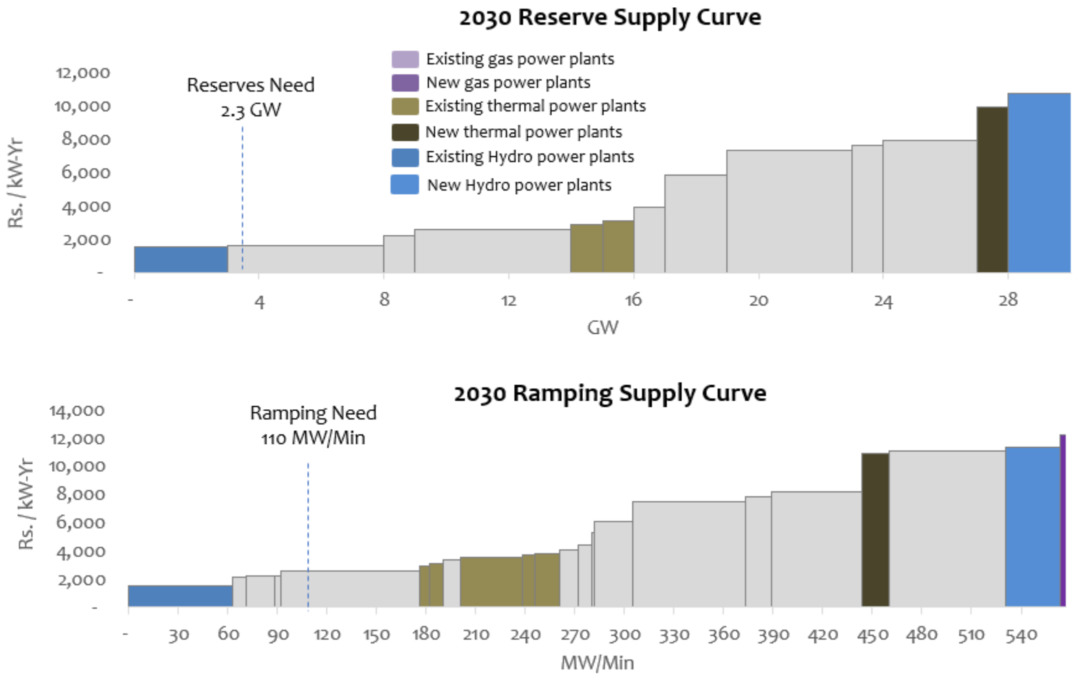
Hydro generation is much more flexible than thermal generation and hence utilised typically for balancing variable renewable generation and unscheduled demand. Karnataka has 3.8GW of non-irrigation-based reservoir hydro capacity including small and mini hydro generation, majority of which is available for flexibility services for the electricity system.

27 All India Electricity Statistics, 2019

28 SRPC, Annual Report 2018-19

Existing hydro is undoubtedly one of the most economic options and has good availability to meet flexibility needs. Along with flexibility from demand, hydro generation capacity is expected to be amongst the cheapest sources of meeting many of Karnataka's flexibility needs by 2030 – daily flexibility (figure 5.15), reserves and ramping (figure 5.16).

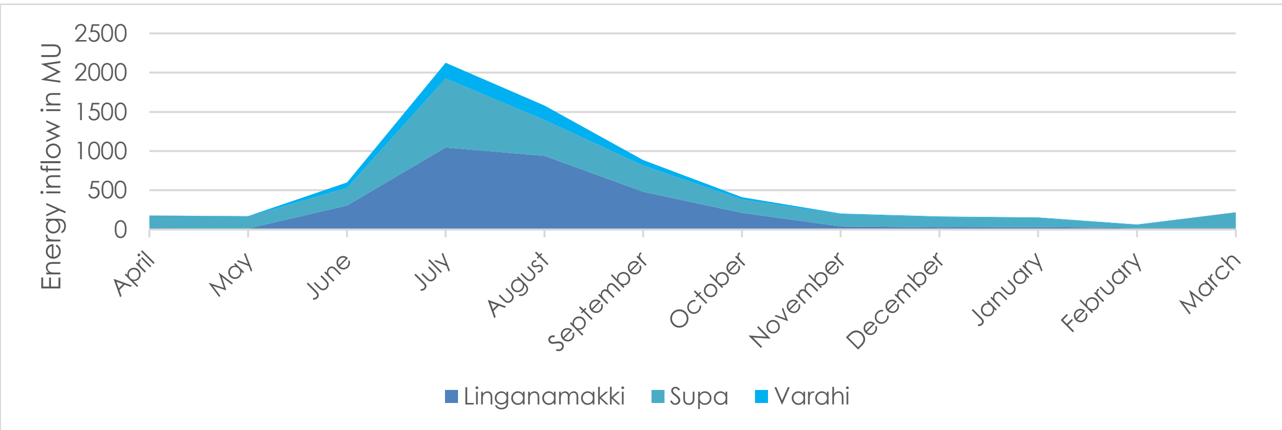
Figure 5.16 Existing power plants, especially hydro powerplants, are a cost-effective source for reserve and ramping



Source: CPI analysis

However, flexible generation from reservoir-based hydro is restricted due to concentrated rainfall during June to October. Inflows into the three major reservoirs in Karnataka rise during the monsoon period (figure 5.17). Reservoir capacity limitations during the monsoon season require certain capacity from these hydro plants to be run as base load during the monsoon months, effectively dampning total flexible capacity, a point at which the state's coal powerplants can be utilized.

Figure 5.17 Inflows into major reservoirs in Karnataka (2017-18)



Source: SRPC, Annual Report, CPI analysis

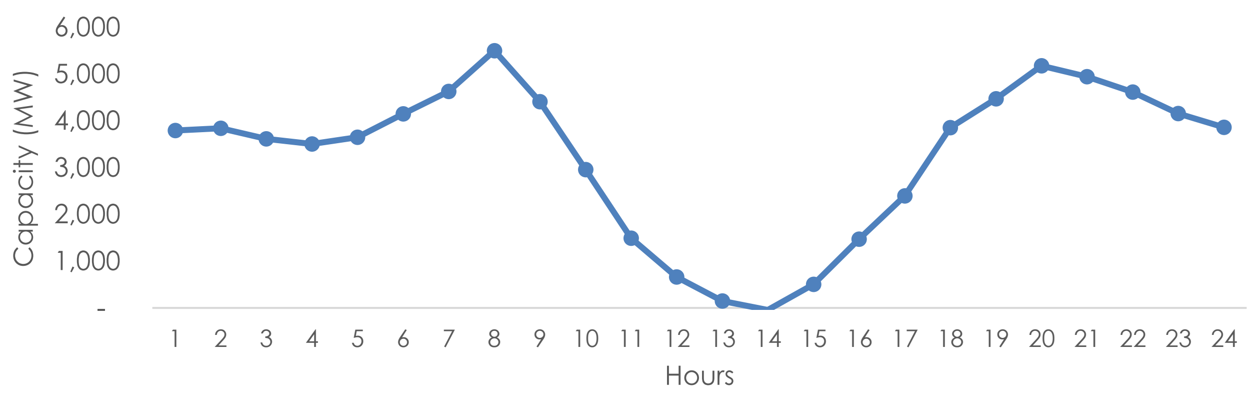
5.3.2 COAL-FIRED POWERPLANTS AND FLEXIBILITY

Karnataka has a combined thermal capacity of 10.4GW, of which 5.0GW is state-owned and 4.2GW contracted from inter-state generating stations, with the remainder contracted through independent power producers. There is no gas-based thermal capacity in the state.

Karnataka's leadership in renewable deployment, especially solar has resulted in some changes in the demands from its powerplant portfolio, especially coal. The solar generation portfolio creates a sharp "duck curve" characteristic on a typical sunny day for Karnataka. Platting the residual demand, demand net of must-run generation, on a typical low wind, sunny day in February shows how the residual demand tapers off as solar generation rises and then tapers off, just as the evening demand is increasing, requiring generation from its powerplant portfolio (figure 5.18). The "duck curve" raises the ramping requirement, which by our analysis is expected to rise by almost 50% to 67MW/min by 2022 and almost 250% to 110MW/min by 2030.

Figure 5.18 Residual demand for non-renewable resources plummets to zero in the middle of the day as solar generation peaks

Residual demand on a typical high solar, low wind day – February 2018

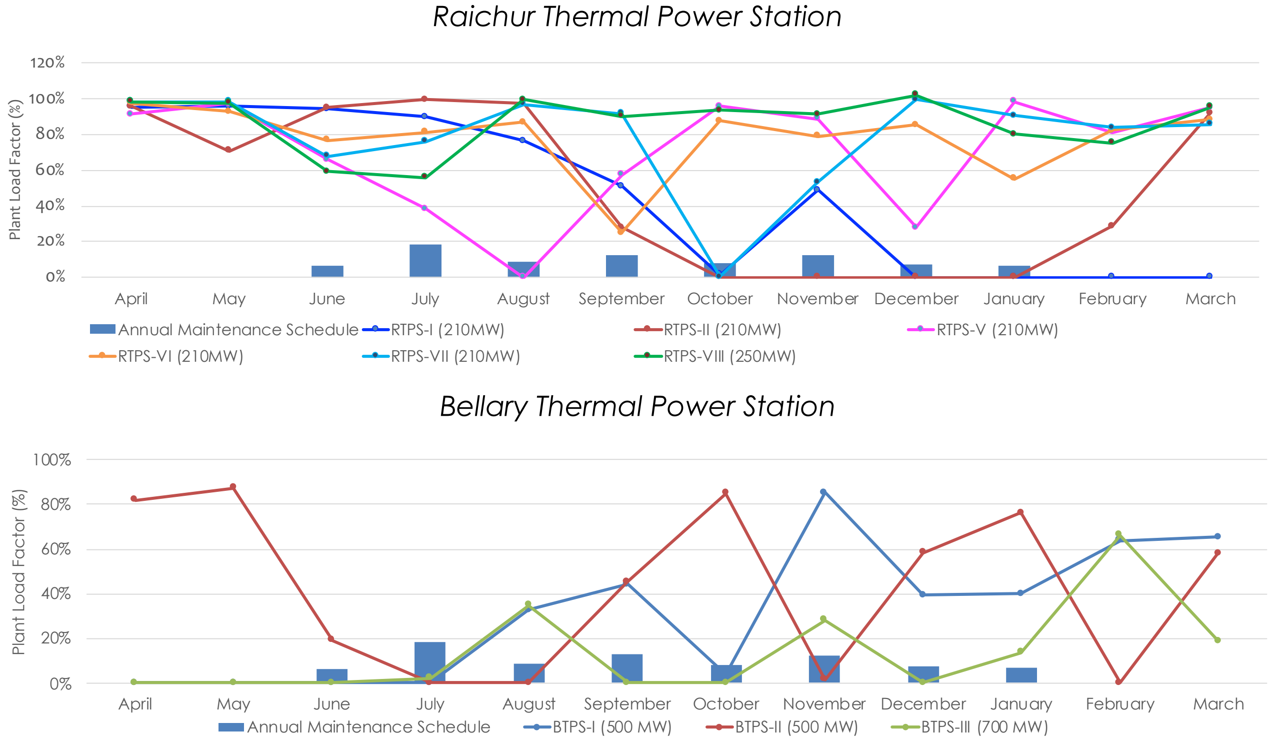


Source: CPI analysis

As we can see from the sample day above, Karnataka has high ramping and daily balancing needs within its current electricity system. With the progressive addition of win capacity, seasonal requirements are also on the rise.

Karnataka's coal powerplants, especially state-owned coal powerplants already do show participation in meeting some of these flexibility needs, especially within their current operational parameters. State-owned thermal powerplants show a drop in utilization during the high-wind, monsoon season (June-October) as maintenance schedules are targeted to overlap with low generation requirements from these powerplants (figure 5.19). State generating stations (compared with central generating stations) are more responsive to meet the seasonal flexibility requirements, as CGS capacity is contracted across different states with varying resources, flexibility requirements and maintenance schedules.

Figure 5.19: State generating station profile (plant load factor) and capacity under maintenance for Karnataka 2018-19



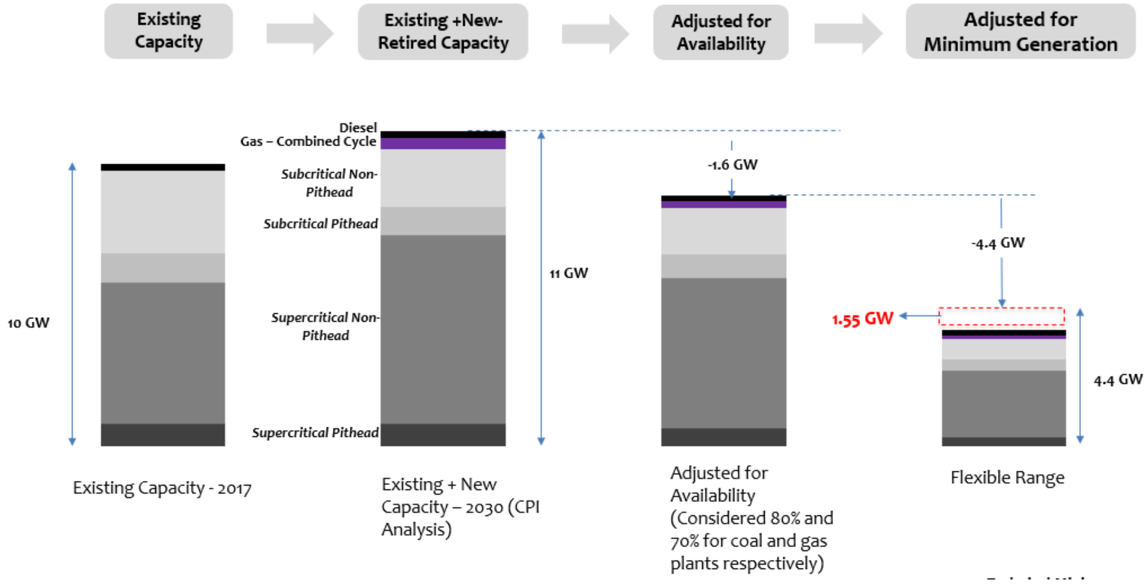
Source: LGBR, 2018-19, CPI analysis

In Karnataka, coal-fired thermal power plants are currently maintained at a technical minimum of 70% and reducing it further would incur additional cost. The state's PLFs are therefore low because plant tend to be turned off, rather than drop below the technical minimum. In theory, the technical minimum adjustments have the potential to supply more thermal flexibility to the system than is currently available today.

Our discussions with Karnataka Power Corporation Limited (KPCL) revealed that Karnataka's state-owned coal plants are able to be effectively operated at technical minimums of 55% based on their design, which is around the same technical minimum as central generating stations. Insight from the NTPC and Siemens team identifies the opportunity to operate coal plants at lower technical minimums, going down to 40%, but that would incur some additional operating costs and higher maintenance costs than current contracts are designed to cover. We estimate that by 2030, Karnataka's coal capacity, owned and contracted can provide up to 4.4GW of flexible capacity, out of which 1.6GW would require plant upgrades and system retrofits. Costs associated with these upgrades could be compensated through contractual arrangements and the removal of production penalties.

We estimated how much flexibility is available by identifying which plants could provide flexibility, adjusting these numbers over time for additions and retirements, then adjusting for availability (that is, maintenance and repair down time), and then adjusting for minimum generation (figure 5.20).

Figure 5.20 Potential flexible capacity from thermal power plants



Source: CPI analysis

The development of thermal flexible capacity is an important step towards integrating high shares of renewable energy into Karnataka's power system. Our analysis shows that under the Current Trajectory Scenario, changing the operational characteristics of the power plants to run flexibly not only reduces excess energy, but also lowers carbon intensity. We found a 5% reduction in overall system costs if plants are operated flexibly as shown in the table 5.7 below which further increases under the blended portfolio scenario.

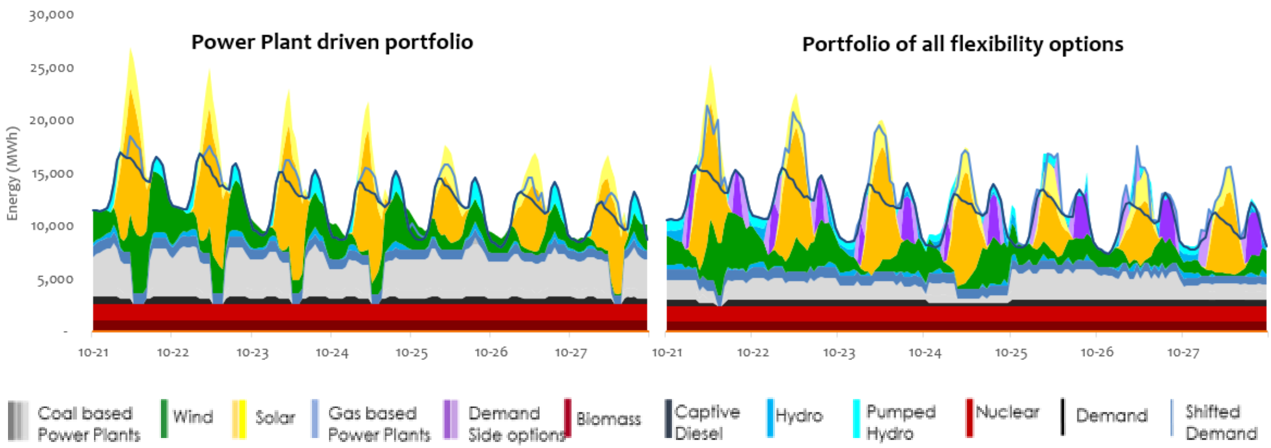
Table 5.7 Summary of changes to flexible operations – Current Trajectory Scenario

Scenario	Implied minimum PLFs	Excess energy	System cost (Rs/kWh)	CO2 emissions (t/MWh)
Base case *Without additional flexibility*	SGS at 70%, CGS at 55%	13.25%	5.5	0.47
Medium powerplant flexibility – with retrofits	All coal capacity at 55%	11.41%	5.3	0.46
High powerplant flexibility - with retrofits	Old SGS at 55%, all CGS and new SGS at 40%	10.89%	5.2	0.45

Source: CPI analysis

Given the availability of many lower cost demand and storage flexibility options, the operation of coal powerplants to meet flexibility needs will depend upon how much of these resources are developed. Figure 5.21 shows how thermal power plant operate differently in a system with a fully developed portfolio of demand and storage options compared with the scenario where power plants are the only source of flexibility.

Figure 5.21: Thermal plant flexibility depends upon the interaction with the other flexibility resources in the system



Source: CPI analysis

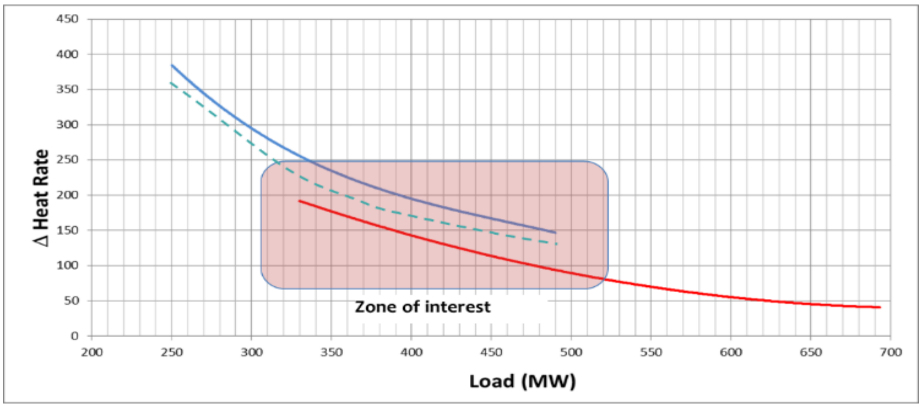
5.3.3 COST OF MEETING FLEXIBILITY NEEDS FROM COAL POWERPLANTS

Flexible operations are restricted by technical and economic constraints as operating plant flexibly below their rated capacity is limited by boiler design and incurs additional cost due to the reduced heat rate (ie, electricity output and therefore Rs/kWh) and increased secondary oil consumption to run the equipment. In order to ensure balancing support to the system, some of the coal powerplants will require the retrofitting of physical components, changing operational parameters, and procedural modifications to achieve lower technical minimum, higher ramp rates and shorter start-up and shut-down cycle.

There are at least four ways that offering flexibility could increase costs to the powerplant.

- **Efficiency penalty:** Operating thermal plants at load lower than its rated capacity reduces its efficiency due to the decrease in the heat rate as shown in figure 5.22, provided by Siemens. We have included 10% efficiency loss at part load. The Central Electricity Regulatory Committee (CERC) notified amendments to the Indian Electricity Grid Code Regulations 2010 that set out a methodology for identifying the stations that should be backed down under specific grid conditions, such as low system demand or high renewable generation. It also set out compensation for additional costs incurred due to the degradation of Station Heat Rate (SHR) and auxiliary consumption.

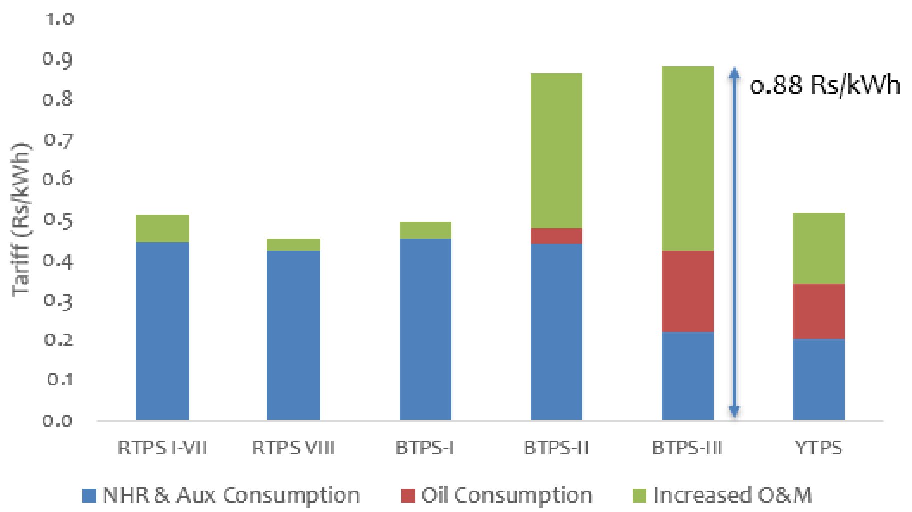
Figure 5.22 Impact of part-load operations on efficiency



Source: Siemens

- **Start-up costs:** The additional fuel consumption due to frequent starts and stops is compensated under CERC regulations to the generator under the Grid Code Regulation. However, the Regulation stipulates that the start-up costs due to reserve shutdown shall be awarded to the buyer who had requisitioned below 55% of their entitlement. If there are more than seven start-stops during the period of operation additional compensation is provided to the generator.
- **Operating cost:** Flexible operations require frequent starts and stops which puts strain on plant equipment and additional costs for maintenance and monitoring. In order to quantify this additional cost, we have factored into our analysis the results of the GTG-RISE Program by M/s Intertek, at Ramagundam TPS and Jhajjar TPS of NTPC[29]. The plant-wise incremental cost due to part load operations for the thermal plants in Karnataka goes up to INR 0.88/kWh as shown in figure 5.23.

Figure 5.23 Additional cost due to part load operation – State generating stations



Source: CPI analysis

- **Capacity**: Providing some flexibility services such as short-term reserve, requires powerplants to operate at less than maximum capacity so that they can increase output quickly in response to sudden surges in net demand. Not only does operating below the maximum increase fuel costs, but additional plants may be required to provide the needed capacity, which would add to system costs.
- **Upgrade cost:** Many plants are not operating as flexibly as they could. Increasing flexibility for these plants requires changes in operating practices, guidelines and incentives. More flexibility can be added to the system through investment. Based on information from Siemens, a retrofit and modernization of a 210MW unit could increase the flexible range by lowering minimum generation levels from 65-70% to as low as 40% while decreasing the fuel cost penalty, lowering ongoing operations and maintenance costs, and extending the life of the plant. Such a retrofit may cost 100 crore INR for a 210MW unit, but 150 crore INR for a much larger 500MW unit.

5.3.4 BARRIERS TO FLEXIBILITY FROM POWERPLANTS

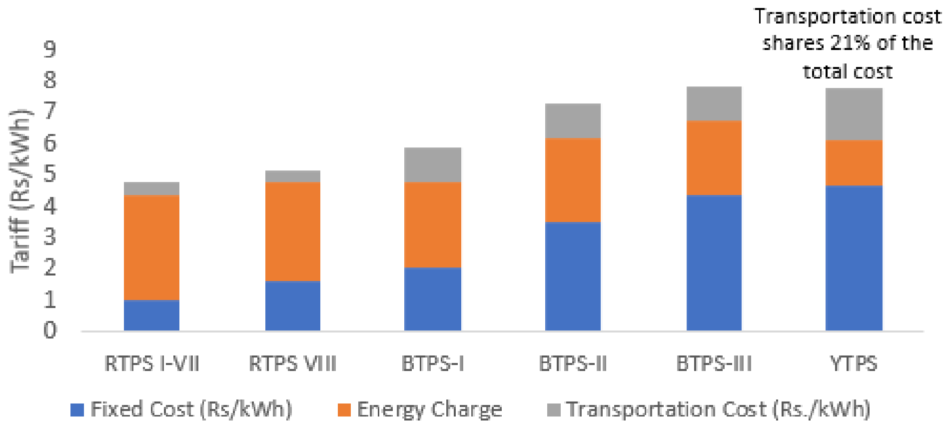
Around 40% of Karnataka's state coal capacity is ageing and based on inefficient sub-critical technology which is limited by design to supply flexibility without retrofitting. Legacy power purchase agreements and contracts for powerplants, especially coal have typically been

29 https://www.gtg-india.com/wp-content/uploads/2019/02/Flexing-Operations-in-Coal-plants_Indian-Scenario.pdf

written to ensure maximum availability of power, with the expectation of the powerplants running as baseload supply sources that can be scheduled to meet demand. However, as we have set out here already, Karnataka's thermal fleet could provide more flexible capacity in addition to what it's already providing. We highlight some of the key challenges that the current contracts create for extracting greater flexibility from powerplants:

- **Cost of fuel and security of supply:** Karnataka does not have any pit-head thermal plant and coal availability has always been a challenge. In Karnataka, 80% of coal demand for thermal generation is met with supply from other states a further 20% is imported from international markets. The total fixed and variable charge even for ageing plants such as Raichur is 4.8Rs/kWh and goes as high as 7.8Rs/kWh for Bellary thermal plant[30]. Transportation costs as a share of variable charges can be as high as 21% (figure 5.24). Relying on distant coal supplies raises the possibility of fuel shortages. In 2017, plants in Karnataka faced severe shortages resulting in expensive procurement from power exchanges.

Figure 5.24 Costs of thermal generation including transportation costs



Source: BESCOM Tariff order, Coal India Ltd, Indian Railways Freight Operations, CPI analysis

- **Scheduling and right to recall**: Existing contracts allow the utility to schedule its contracted power in up to four-time blocks before delivery. This limits the amount of surplus electricity that generators can sell to the market, restricting their participation on power exchanges and reducing their opportunities for cost recovery.
- **Limited incentives:** Even when the generator sells power in the market, the contracts place an obligation on the generator to share two-thirds of the profits with the utility. With the introduction of real-time markets, the right to recall the contracted power by the utility has been increased to seven time-blocks, but the profit sharing remains the same, which reduces incentive for the generators to operate flexibly.
- **Auxiliary consumption**: The more thermal power plants operate flexibly, the more the plant consumes electricity for its own operations. Auxiliary consumption is usually netted off from the energy supplied by the generator to the utility. The increase in auxiliary consumption due to part loading is not compensated for under the current state regulation.
- **Additional capex**: Existing contracts provide that any additional capital expenditure for renovation, refurbishing and modernization shall be passed through to the state utility

30 BESCOM Tariff Order – 2018-19, KERC

subject to the regulator's approval. There is no clarity on pass through of any refurbishing costs to increase the flexible operation of the thermal plants

5.3.5 MARKET REFORM & INTEGRATION FOR POWERPLANT FLEXIBILITY

Karnataka has already made a strong start on the development of an electricity power system that is reliable, affordable, low carbon – and also fit for the state's ambitions on economic growth. But the system will require a two-step approach: first it must maximise the flexibility capacity of existing and emerging sources of flexibility; second it must introduce incentives and policy interventions that can integrate the technologies to maximise the economic benefits and efficiencies of a high renewables system.

Today, thermal power plants are incentivized more for availability than flexibility. With modifications to regulations, operations and contractual frameworks, our analysis has found that further flexible capacity could be provided, especially to meet Karnataka's growing need for daily shifting and ramping. Thermal plants are already meeting the emerging seasonal balancing needs by coordinating maintenance schedules with period of peak wind and hydro generation during the monsoons. However, on its own this approach will not produce enough ramping and daily shifting capacity. Hydro has limited options to expand and its peak capacity corresponds with peak wind generation rather than peak flexibility need.

But even these resources, currently most often used as baseload, could provide a wider range of high value flexibility services (such as ancillary services) if the right incentives are put in place, and contractual arrangements are more aligned with providing flexibility than baseload. While there are a few specific examples where increasing the flexibility from some assets may prove a challenge, a technical assessment of the powerplant portfolio, generator by generator, to identify plant flexibility potential and costs would be an important first step. A full review of existing contract types could inform the development of new contractual arrangements that better reflect the needs of a flexible grid and include cost recovery for investments such as plant upgrades.

It is clear that there is a widespread need for further technologies that would enable greater flexibility, such as Automated Generation Control (AGC) and communications system that can transmit information on supply and demand to form transparent price signals for highly efficient markets. Data will be at the heart of developing enough information for such markets. India is at the start of this journey in data provision within the power sector, and its progress in this area lags behind its progress in renewables deployment. In the near future, the lack of data at asset and system level will become an impediment to delivering its renewable targets at the maximum efficiency and lowest cost. Karnataka is well placed to implement initiatives to go further, encouraging transparency by mandating the provision of data and creating a platform where it can be shared.

Policymakers in Karnataka could provide a regulatory and policy framework to create an ecosystem that incentivizes the flexible power plant operations by taking the following approaches:

1. State Grid Code Regulations for Karnataka need to be amended to allow recovery of costs for flexible operation of powerplants. To facilitate the flexible thermal operations, there is a need to determine the increase/degradation of Heat Rate/Auxiliary consumption and additional oil consumption due to partial loading of the generating unit and assigning a compensation mechanism under the scheduling and Dispatch clause of State Grid Code Regulation.

2. For regulated generators, tariffs are determined based on Multi-Year Tariff Regulations, decided by the Regulator which needs to be amended to account for/allow pass through of additional cost of flexible operation based on the compensation mechanism stipulated under the proposed amendment in State Grid Code Regulation.

3. Introduction of capacity mechanisms and capacity markets to precontract reserve and flexibility capacity from coal powerplants has previously been utilised in the UK and can help Karnataka make an investment case for procuring dedicated capacities for flexibility

4. Existing PPAs will need to be mutually renegotiated where the adjustment on energy charges on account of variation in fuel cost should also include the additional cost due to flexible operation as per the direction of the SLDC and norms as specified in the State Electricity Grid Code.

5. For pipeline capacity, the PPA terms should set the parameters of the contracts around flexibility, allowing cost recovery for higher Station Heat Rate and auxiliary consumption, higher fuel consumption, plus a capex plan that allows for maintenance capex in line with wear and tear.

6. The Central Electricity Regulatory Commission (Ancillary Services Operations) Regulations, 2015, should be amended to allow participation of all the generating entities irrespective of their type, ownership and location. This would provide access to market-based ancillary services which eventually allows for price discovery and the trade of flexible capacity, creating additional revenue streams and providing cost recovery for both contracted plants and merchant generators.

6. Summary & Recommendations

Karnataka can continue to be a leader in India's perusal of renewable energy targets, but concerted action on harnessing the near-term opportunities and clear planning to lay down a roadmap for developing each of the flexibility options and integrating them is essential.

6.1.1 OPPORTUNITIES TO DELIVER HIGHER FLEXIBLE CAPACITY IN THE NEAR-TERM

1. **Enhance flexibility from coal-fired powerplants**
    - o Powerplants are already a source of flexibility for Karnataka. Utilisation of both hydro and coal for flexibility can help optimise the existing capacities and for coal, accessible fuel
    - o Targeting enhanced power plant flexibility for Karnataka will deliver an additional 15% of the coal portfolio in the near term as plants lower their utilisation to 55%. Targeting 40% technical minimum will release another 15% of the plant capacity, especially for newer / retrofitted state plants as well as central generating stations
    - o Karnataka will also benefit from two shifting of coal plants, considering the diurnal nature of solar generation, and resulting daily shifting and ramping needs
    - o Older units of RTPS, not yet ready for retirement can be categorised for seasonal use
    - ➔ The enhanced power plant flexible capacity will important for meeting the intraday balancing and ramping requirements, reducing the need for curtailment and hence systems costs. It will also be key to creating the capacity to meet seasonal balancing needs from incremental addition of wind capacity in the portfolio
    - ➔ Regulatory updates and update of current contractual agreements with coal powerplants to accommodate flexible operation of powerplants and recovery of additional costs would be key
2. **Expand agriculture flexibility**
    - ➔ The separation of agriculture feeders has already been implemented successfully in certain states in India and is almost 55% complete for Karnataka. One of the key steps for Karnataka would be to complete the feeder separation for separation of the agriculture pumping load for shifting and ramping
    - ➔ Under KUSUM scheme transfer of agriculture load to grid-connected solar pumps will keep the load on the grid for flexibility, for scheduling and managing the grid
3. **Procure grid level storage**
    - o The highest impact storage solutions for a state that is in early stages of implementation of storage would be the suite of services that could be delivered by its deployment at distribution substations.
    - ➔ In the short term, nodes for deployment can be identified by the combined knowledge of the discom teams and KPCL, to address bottlenecks and assist distribution capex deferral.

- ➔ In the longer run, we would recommend data collection by feeders to systematically identify and deploy future storage capacity.
- ➔ Karnataka could partner with multilaterals to support initial pilots and project procurement

6.1.2 STEPS THAT CAN BE TAKEN NOW TO DELIVER HIGHER FLEXIBLE CAPACITY IN THE MEDIUM TO LONG TERM

There are some longer term tools and technologies with potential to make a significant impact on the flexibility availability for Karnataka but these options will need targeted approach today in the form of pilots, mandated procurement of limited capacity to test appetite, to send market signals and help deliver the cornerstone for the markets to deliver scale effects that bring down costs and create the pathway for effective integration of the flexibility options.

Karnataka can target three opportunities to nurture and develop, such that steps taken now can deliver higher flexible capacity in the medium to long term:

1. **Procure behind the meter (BTM) storage capacity, especially large-scale**
    - o An important flexibility option this procurement will target large commercials and Industries with sizeable backup capacities, to consolidate backup reserves from batteries and the diesel genset capacities that are already present. This engagement will set the parameters for the targeting of the BTM large scale backup capacity, to understand the incentive structures to engage the large-scale C&I partners.
    - ➔ Contract with larger back-up storage capacities to access for flexibility services, especially daily shifting
    - ➔ Pilot and test pricing mechanisms and incentive structures
    - ➔ Incentivise transition of back-up storage, especially large scale backup from diesel gensets to battery storage
2. **Run pilots for demand flexibility**
    - ➔ Industrial flexibility - To fully develop the scope of industry flexibility, pilots will need to be structured that can target direct contracting with the industry partners to set and test parameters and incentive structures that would make such arrangements attractive.
    - ➔ EV charging – Pilots for different charging and battery swapping models built up on local and commercial chargers, to set and test pricing and incentive structures that customers respond to in different segments
3. **Market design that integrates initiatives**
    - o Build electricity markets that integrate new and existing resources at least cost
        - ▪ more robust day ahead markets,
        - ▪ ancillary services,
        - ▪ seasonal contracts,
        - ▪ capacity markets, etc
    - o Enhance learning by doing, e.g. storage manufacturing, to slowly build relevant capacity, incentives and market signals and integrate them into existing structures

6.1.3 MARKET DESIGN INITIATIVES AND INCENTIVES

From our analysis and assessment of the role of market reform across each of the options, we believe the following market design initiatives and incentives will need to be targeted over the near term:

1. Adjustment of regulations and contracts to allow recovery of full cost of powerplant flexibility, and removing the nominal technical minimum as a basis of calculation of the recovery of sunk costs
2. Evolution of the Ancillary Services market to allow access to all sizes of 'Flexible capacity' buyers and sellers and scope for price discovery
3. Nodal cost assessments for assessing optimum locations of grid battery storage
4. Development of income algorithm for grid battery storage developer to attract private investors and multilateral financiers, and development of pilots
5. Development of pricing structures and overlay of incentives to target participation of BTM captive generation as well as backup capacity in flexibility services
6. Capacity market mechanism to procure reserves, for diurnal and seasonal needs.
7. Last but not least, there is a need for the development of a 'data mission' for Karnataka so that different data points that are crucial for decision making can be available such as the nodal data for grid load for locational pricing to encourage development of grid capacity where its most needed.

Annex 1: Figures & tables

Figures

Tables

Annex 3 – Acronyms

BNEF	Bloomberg New Energy Finance
BTM	Behind the Meter
BU	Billion Units
CAGR	Compound Annual Growth Rate
CCGT	Combined Cycle Gas Turbine
CERC	Central Electricity Regulatory Commission
CII	Confederation of Indian Industry
CPS	Current Policy Scenario
CTS	Current Trajectory Scenario
DSM	Deviation Settlement Mechanism
ECR	Energy Charge Rate
EPC	Engineering Procurement and Construction
EPS	Electric Power Survey
ESCO	Energy Service Company
EV	Electric Vehicle
FTR	Financial Transmission Rights
GDP	Gross Domestic Product
HRE	High Renewable Energy
HSRG	Heat Recovery System Generator
IEA	International Energy Agency
IESA	India Energy Storage Alliance
IPP	Independent Power Producer
K-G	Kaveri-Godavari
KUSUM	Kisan Urja Suraksha evam Uttan Mahabhiyan
LDV	Light Duty Vehicle

LMP	Locational Marginal Price
LNG	Liquified Natural Gas
LSHS	Low Sulphur Heavy Stock
LTOA	Long-term Open Access
MTOA	Medium-term Open Access
MU	Million Units
NCTPS	North Chennai Thermal Power Stations
NLC	Neyveli Lignite Corporation
NTPC	National Thermal Power Corporation
OEMs	Original Equipment Manufacturer
O&M	Operations & Maintenance
PLF	Plant Load Factor
POSOCO	Power System Operation Corporation
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
SCADA	Supervisory Control and Data Acquisition
SHR	Station Heat Rate
SLDC	State Load Dispatch Centre
TANGEDCO	Tamil Nadu Generation and Distribution Corporation
TANTRANSCO	Tamil Nadu Transmission Corporation
TNLDC	Tamil Nadu Load dispatch Centre
T&D	Transmission & Distribution
VTG	Vehicle to Grid