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Electricity market reform – Tamil Nadu case study

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Descriptors

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

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

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Executive summary

With the appropriate market mechanisms, technologies, incentives, and infrastructure in place, Tamil Nadu can meet the challenge of reducing the cost of energy supply to consumers, while increasing system reliability and dramatically lowering carbon emissions.

Tamil Nadu has been at the forefront of India's ambitious decarbonisation programme, which aims to reduce emissions while meeting energy demand and supporting economic growth. Thanks to the country's rapid deployment of renewables, India is on target to meet its carbon reduction targets agreed under the Paris accord in 2015[1]. The state has already installed 14GW of renewable energy capacity, 16% of India's total, and has growth targets that could increase the supply of clean energy threefold by 2030. Like the rest of the country, Tamil Nadu is at a critical inflection point with respect to electricity market design and electricity industry structure.

Previous analysis for the Energy Transitions Commission showed that for generic electricity systems[2], as well as for India when taken as a whole[3], the total system cost of a high renewable, 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 demand and supply 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 flexibility supply and demand and the need to evaluate options and plans at a state level to fully understand the costs, potential, and issues that might 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 Tamil Nadu, and India as a whole, to meet this challenge.

In this case study, we have:

- Assessed the cost, development, capital requirements and timing of potential flexibility options – including powerplant flexibility, demand flexibility, and energy storage – through to 2030 across three main scenarios – Current Trajectory, Current Policy and High Renewables, which eliminates 4.8GW of the coal pipeline capacity, while retaining the 3.4GW currently under construction.
- Modelled the dispatch of the Tamil Nadu electricity system in 2030 using different mixes of flexibility options and generation capacity additions to determine the impact of these mixes on cost, carbon emissions, wasted excess renewable energy production and potential load shedding.
- Identified development needs and market mechanisms that could help Tamil Nadu 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 in the rest of the country. In the absence of greater flexibility through planning and market reforms, by 2030 renewable energy generators supplying to Tamil Nadu could be curtailed by as much as 15-20%, more than double the Indian average. Thermal generation would see strong variations in its monthly load factors, with expected load factors falling below 1% in some months, without any route to cost recovery.

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[1] 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.

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

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

Four main findings have emerged from this work:

1. **Flexible energy markets reduce cost and emissions.** If Tamil Nadu 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 13%, while reducing carbon emissions by up to 17%.
2. **A portfolio of flexibility options provides the most promise.** Flexibility in 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.** The system cost for Tamil Nadu could fall a further 6% with integration into an India wide market.
4. **Developing appropriate market mechanisms to encourage development of flexibility options Is critical**

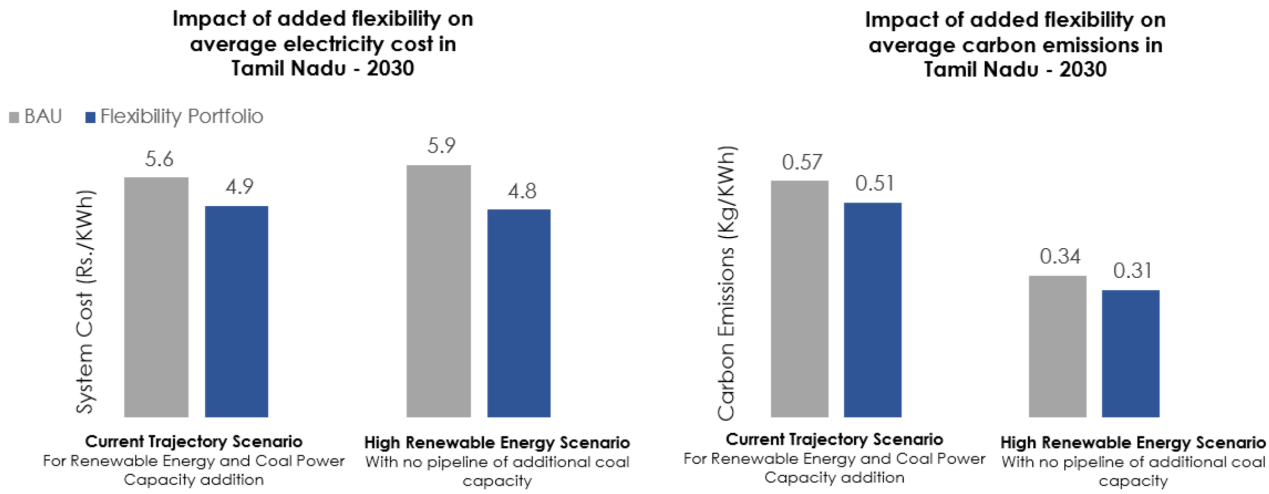
Finding 1. Flexible energy markets reduce costs in Tamil Nadu

Even without access to inter-state or regional power markets, we find that the development of flexible generation capacity, flexible demand, and energy storage, can reduce system costs even if Tamil Nadu fails to meet or exceed its ambitious renewable energy targets.

To focus on the value, supply, and demand for flexibility in Tamil Nadu, we began our analysis by modelling the extreme case where Tamil Nadu 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. Likely results are somewhere in between.

For an isolated Tamil Nadu system, we found that enhanced flexibility can reduce average electricity costs by up to 13% and carbon emissions by up to 17%, as in figure ES1.

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



Source: CPI Energy Finance

Our analysis was based on estimates of the cost and potential flexibility capacity in Tamil Nadu, including that provided by enhanced flexibility from powerplants, the participation of consumers in energy markets and battery storage. 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 energy scenarios, when combined with higher flexibility, allowed a reduction in the amount of new coal fired capacity built in the state, without sacrificing reliability and supply. Thus, we eliminated the pipeline of 4.8GW coal capacity for Tamil Nadu, while retaining the 3.4GW of assets under construction.

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.

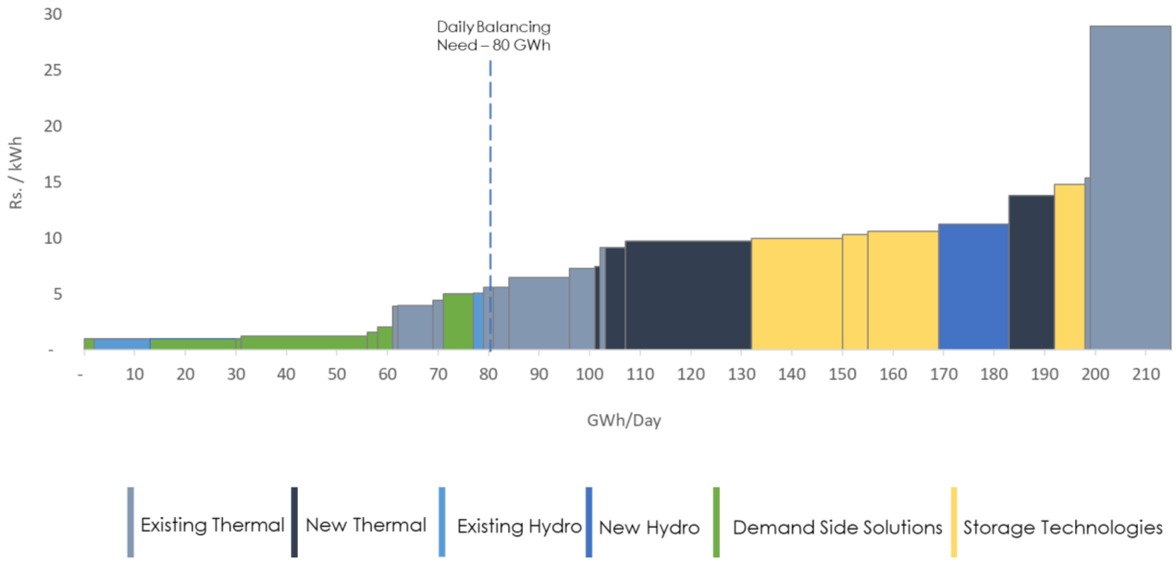
Finding 2: A portfolio of flexibility options provides the most promise.

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

- **Demand flexibility.** Increasing the ability of industrial, residential and commercial 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.
- **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 output to a season with higher demand. Figure ES2 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 Tamil Nadu 2030



Source: CPI Energy Finance

Figure ES2 shows how the costs of flexibility from thermal and hydro powerplants, demand flexibility and storage 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 flexible charging of electric vehicles (mainly 3 wheelers). Other flexibility needs have different patterns, with different mixes of demand, powerplants and storage providing the lowest cost set of options.

Across the various sets of flexibility resources and flexibility needs we find that:

- **Demand flexibility** is generally the least expensive new resource.

- **EV charging** presents one of the cheapest forms of flexibility across many of the flexibility needs, but access to this flexibility will require careful development of business models, incentives with real time pricing, charging infrastructure, and EV design, particularly for 3 wheeled vehicles.
- **Agriculture** represents 15% of demand in Tamil Nadu and flexible operation of pumping provides another low-cost opportunity, but one that requires separation of agricultural feeders, new metering and pricing schemes and incentives for agricultural consumers, and control systems.
- **Space cooling** is a third option with a high potential for reserves and ramping, similar to EV charging and agricultural pumping, given the rapid forecast growth in cooling demand. However, potential for daily shifting is much lower. Incentives, metering, behaviour change are all issues here that need to be addressed.
- **Industry** consumes 30-45% of Tamil Nadu's electricity supply, depending on the time of year. Options to shift the demand and provide flexibility are very dependent on industry segment and facility. We estimate that industrial flexibility potential is roughly half that of pumping or EV charging for reserves of ramping, and much less for 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 one of the least expensive paths to seasonal flexibility.

Our analysis focused on these four categories of demand flexibility, though many other demand resources exist that could be accessed through generic demand side programmes. Furthermore, our experience is that the response of consumers is unpredictable, so we have taken conservative estimates of potential. Thus, we believe that our estimates for potential are likely to be low. That having been said, given the unpredictable nature of consumers, it could be tricky to achieve high levels of demand flexibility without a serious and concerted programme that starts early.

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. Battery storage is also the option that is least dependent on local conditions. Whereas demand flexibility depends on the mix of consumers, their equipment and even the weather, and powerplant flexibility depends on the powerplants 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, despite an 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, low variable cost option which is most attractive when the capital costs can be used in recurring cycles where the capital costs can be amortized over may uses. Additionally, storage economics improve further 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 electric vehicle 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 demand flexibility. 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. Coal and hydroelectric powerplants already provide the bulk of Tamil Nadu's system flexibility. However, with the right incentives, contract modifications, markets signals, and in some cases investment, there is further potential. For example, lowering 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 7GW of flexibility capacity to the system, 600MW of which would require plant upgrades and changes in the cost recovery mechanisms and 1.98GW of coal capacity will need to be retrofitted for maximum flexibility, running coal plants down to a technical minimum of 40%. Further flexibility could be added by enabling overnight shutdown of plants, which requires study and investment. This potential is not included in our analysis.

The flexibility potential of older coal powerplants is 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 centre and IPPs adjust to run at 40%. Overall, we believe, coal powerplants has the potential to make significant contributions to flexible capacity in the immediate term and as Tamil Nadu 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. The timing of the upgrades could be planned in response to the success level in achieving greater demand flexibility. Short term incentives are unlikely to be enough to encourage major retrofits or operating changes, 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. Demand, storage and powerplant 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 an 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. Table ES1 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 incremental flexibility needs. These models assess the impact on excess energy – that is renewable energy that is wasted during times of excess generation – average system electricity cost and carbon dioxide emissions.

Figure ES3: Portfolio approach to flexibility delivers the highest optimisation on curtailment reduction, CO2 emissions and amongst the lowest system costs

Current Trajectory Scenario

	Excess Energy	System Cost	CO2
Base Case	4.7%	5.587 (Rs./KWh)	0.566 (t/MWh)
Fossil Flex	-9.4%	-9.9%	2.1%
Storage Flex	-66.4%	-9.3%	-2.7%
Demand Flex	-62.5%	-13.1%	-5.1%
Portfolio	-69.2%	-11.8%	-9.2%

High RE Scenario – No pipeline coal Capacity

	Excess Energy	System Cost	CO2
Base Case	20.9%	5.892 (Rs./KWh)	0.340 (t/MWh)
Fossil Flex	-0.8%	-9.7%	8.4%
Storage Flex	-14.2%	-12.9%	0.0%
Demand Flex	-16.9%	-18.2%	-5.7%
Portfolio	-27.3%	-17.0%	-9.5%

Source: CPI Energy Finance

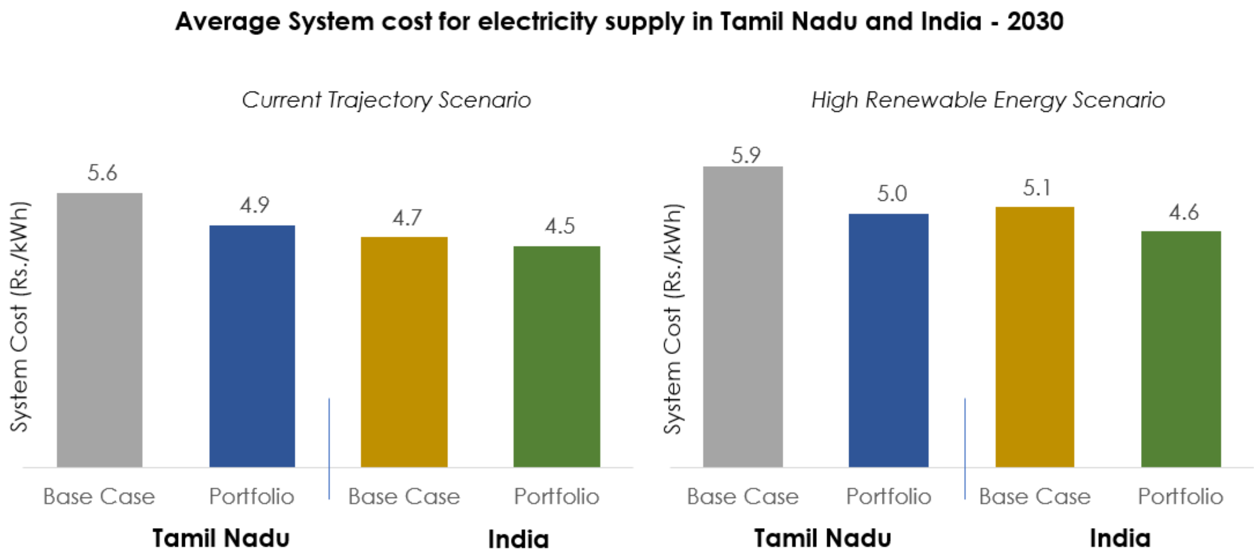
The results indicate that meeting all incremental flexibility needs through demand flexibility would be the lowest cost solution. However, using a portfolio of options leads to further reductions in excess energy and carbon emissions. Furthermore, the portfolio will provide greater security in development, as failures to meet demand flexibility 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 Tamil Nadu 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 Tamil Nadu could be a further 6% lower with perfect integration into an India wide market. Tamil Nadu will need strong transmission linkages and participation in regional and trading and exchanges to fully harness the benefit of its high renewable portfolio. Tamil Nadu's ability to transact flexibility would be value accretive as well as reduce the need for curtailment even under High RE scenarios.

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



Source: CPI Energy Finance

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 proportion of the 6% further benefit is achieved given today's levels of integration.

Connectivity will also alleviate the pressure on Tamil Nadu's existing flexibility resources that will escalate from the middle of the 2020s without action. These flexibility resources have the potential to add value to the state's excess capacity from wind generation. If well integrated with national power systems, a high HRE scenario also eliminates the need for expensive and carbon intensive diesel generation (see ES4 above).

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

In our report on electricity market development and flexibility options for India,[4] 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 country's

[4] Developing a roadmap to a flexible, low-carbon Indian electricity system https://www.climatepolicyinitiative.org/publication/developing-a-roadmap-to-a-flexiblelow%e2%80%90carbon-indian-electricity-system/

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. Our review of Tamil Nadu indicated that most of the requirements at the India level are mirrored by needs in Tamil Nadu, although differences in circumstances inevitably lead to different emphasis and focus. In Figure ES5 we set out the issues and systems/incentives that Tamil Nadu should address in the short term and in the longer term.

Taken together, these actions should put Tami Nadu on course for a lower cost and cleaner electricity system, but also an important contributor to improvements in India's energy system.

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

<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="2">India and TN 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</td><td>TN could benefit from pilot programmes:
• Agricultural pumping – feeder separation vs incentives
• Commercial space cooling – automated access
• Cold storage
• EV charging models
• Industrial flexibility management – contracts vs incentives</td><td rowspan="3">TN 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 industrial customers of flexibility opportunities and ways of accessing value

Develop consumer awareness

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 seasonal and daily load shifting contracts with industry

Create and negotiate contracts for daily shifting with commercial cooling load

Pricing mechanism along with an incentive/ penalty for EV charging</td><td>Develop a long-term model for the Tamil Nadu electricity system design – potentially working with national players - that gives flexibility resource developers confidence in the future demand for flexibility services</td></tr>
<tr><td>Storage

Develop and install</td><td>Pilot programmes for battery storage:
• Substation/Grid
• Distribution system
• Backup/Diesel replacement
• Ramping assistance</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 Tamil Nadu storage development/ manufacturing / operating companies – either as part of TANGEDCO as well as separate private developers</td><td rowspan="4">Create transition markets that accelerate the development of flexibility options</td></tr>
<tr><td>Powerplants

Encourage operation and regulatory changes and investment</td><td>This data would be essential input into building additional flexibility capacity and evaluating the value of options and programmes</td><td>Pilot programmes to assess costs & potential for each category of powerplants to:
• Operate more seasonally
• Lower minimum generation to improve ramping and shifting</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 seasonal resource</td></tr>
<tr><td>Transmission

Continue expanding with flexibility needs</td><td colspan="6">Tamil Nadu 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.
TN 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. TN may wish to begin developing state level locational markets to improve intrastate flexibility and reduce state level distribution and transmission costs and constraints.</td></tr>
<tr><td>Integration

of options to minimize cost</td><td colspan="6">Tamil Nadu will be one of the first states to experience significant issues with respect to flexibility and therefore should be a leader in pulling together a complete package of programmes. TN should develop a comprehensive plan that includes incentives and markets for development of the options, alongside markets and infrastructure build 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

Tamil Nadu has the highest installed wind capacity and the second highest capacity of renewables in India, making the country's southernmost state a critical player in India's renewable ambitions.[5] In 2018, 43% of Tamil Nadu's 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 this populous and industrialised state over the coming decade.

The state's energy portfolio is diverse, with 10.4GW of thermal capacity (5.2GW state-owned, 5.2GW contracted from IPPs, NLC India and NTPC), with plans for an additional 6.6GW net of retirements by 2030[6]. The state benefits from 2.3GW of hydro capacity, including pumped hydro, which is expected to almost double by 2030. Low-cost domestic gas along with 2.7GW of nuclear and biomass provide mostly baseload power. The state has been at the forefront of India's wind revolution, with 9.3GW capacity representing a quarter of installed capacity in India, almost double the next highest wind state, Rajasthan. Solar has been slower to take off in the state, but its 2022 targets should take it to 9GW of installed solar capacity.

However, difficulty in integrating these resources, has started creating challenges for grid balancing, forcing high utilization of the deviation settlement mechanism (DSM) by Tamil Nadu. Curtailment is a real challenge for renewable energy, threatening the economics of wind and solar projects. Meanwhile, thermal plants have seen their load factor fall during high renewable generation periods, hurting economics across the electricity sector and creating resistance to further renewable energy deployment. In future, the cost of meeting its electricity needs is likely to increase as more intermittent wind and solar are added.

This paper is a continuation from our previous work for both the India and global Energy Transitions Commission where we concluded that high levels of additional flexibility would be paramount to delivering lower system costs for a high renewable, low carbon electricity system. We now look at the flexibility options for Tamil Nadu, 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 this flexibility and efficiently integrate 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 Tamil Nadu's flexibility needs.
- **Section 4** summarises how the flexibility options for Tamil Nadu come together into portfolios and what it means for costs, need for curtailment and CO_2 emissions.
- **Section 5** is a detailed dive into the flexibility options. After assessing the potential and cost of flexibility options, we investigate what barriers exist to accessing their potential and the role of market reforms in resolving these.
- Sixth and **final section** is transition roadmap for Tamil Nadu, outlining the transitions that the state needs to deliver these options, some converting potential now and others which are necessary to plan and implement now to deliver further flexible capacity by 2030.

[5] India has a target to install 175GW of renewable energy by 2022, and a further target of 450GW by 2030

[6] TNEB Statistics 2018

2. Framework & methodology

Our findings are based on the cost, resource potential of various electricity system flexibility options in Tamil Nadu, 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.

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

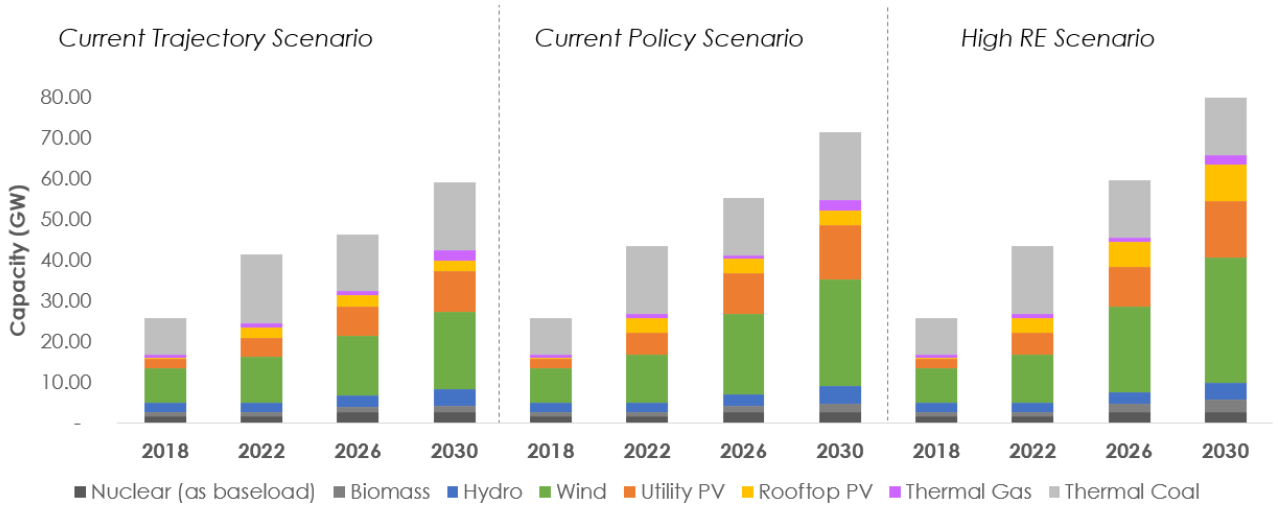
1. **Challenges**. What are the most important challenges for the electricity system in Tamil Nadu now and in the future? How and why are they different than at the national level?
2. **Technology options**. What options can technology/ business provide and what is the local need / market for these services?
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

We start with future scenarios of possible energy mixes in the India power system. These scenarios include different proportions of energy supplied by variable renewable energy and thermal powerplants, as these are two main determinants of how much flexibility the system will need. The following three scenarios have been considered (Figure 2.1):

- **Current trajectory scenario (CTS)** based on forecasts of future renewable energy deployment following current trends;
- **Current policy scenario (CPS)** where Tamil Nadu meets the government's current renewable energy targets to 2022 and further renewable energy deployment at the same rate to 2030;
- **High renewable energy scenario (HRE)** where Tamil Nadu accelerates renewable energy deployment to align with the national target of 450GW by 2030.

Figure 2.1: Renewable Energy Scenarios for Tamil Nadu



Source: CPI Energy Finance

Out of Tamil Nadu's 10.4GW thermal portfolio, 2.9GW is expected to retire before 2030, reducing the state owed capacity to 3.4GW and capacity contracted from IPPS, NLC and NTPC to 4.2GW. Tamil Nadu also expects to add 1.5GW of LNG based CCGT and 8.2GW of coal capacity by 2030, 3.4GW of which is already under construction, whereas 4.8GW of the pipeline stands at various stages of development.

For the scenarios with higher renewable energy deployments and hence high amounts of excess energy, ie, CPS and HRE, we have considered modified generation capacity scenarios, eliminating 50-10% of the coal pipeline under development for Tamil Nadu.

- **CPS – 50% coal pipeline**. Tamil Nadu retains the renewable capacity mix of CPS but reduces its coal capacity for 2030 by 2.4GW, ie 50% of the coal pipeline.
- **HRE – 100% coal pipeline.** Tamil Nadu retains the renewable capacity mix of HRE but reduces its coal capacity for 2030 by 4.8GW, ie 100% of the coal pipeline.

2.2 Assessment of flexibility needs

For each of the three renewable energy scenarios, we assess the development of different flexibility needs. The flexibility requirements were analysed on a timeline based between 2018 and 2030. The demand profile for 2018-19 was received from TANGEDCO. The demand profile for 2030-31 was based on 2013-14[7] load profile 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 Tamil Nadu'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;
- **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

[7] 2013-14 to align with base year chosen by NREL for wind and solar production profiles projection.

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 to maintain the required match of supply and demand across the year. In Tamil Nadu, the most significant need results from the monsoon, when wind generation is high, and the resulting excess generation needs to be shifted to months when demand outstrips supply.

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 Tamil Nadu can harness from demand. The lack of comprehensive end-use data on energy consumed, load patterns, price sensitivity, customer attitudes and other data needs hampers 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, agricultural pumping, space cooling (commercial and domestic), industrial demand and EV charging. 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 break the 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 the life of batteries and the life of batteries. We used the estimates for each of these variables, and the investment return required, to calculate the cost of providing flexibility services through storage options under different ownership models at today's costs and operating characteristics we forecast for 2030.
- **Powerplant flexibility**. Most flexibility today is provided by thermal and hydroelectric powerplants. 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. 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. 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 Tamil Nadu, can deliver significantly more flexibility thanthey do currently. Without modification, experts suggest that the plants can offer more flexibility by changing operational practices. Investment in retrofits can also significantly increase the amount of flexibility each plant can offer. We worked with the Siemens India team to evaluate the cost and potential of retrofits and we 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 Tamil Nadu 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 Tamil Nadu can implement the programmes and market reform needed to develop the flexibility options.

2.4 Power system modelling and integrated portfolios of flexibility options

Supply curves

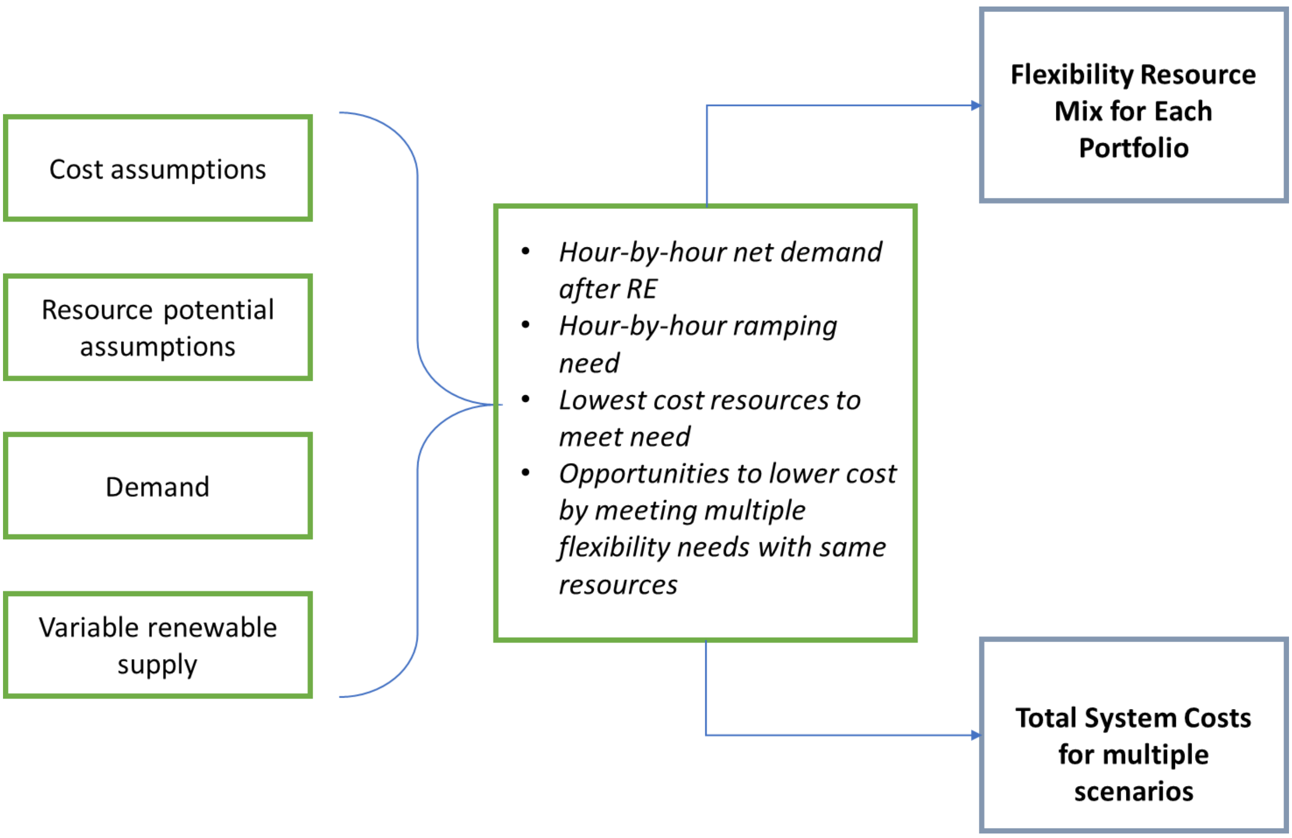
With the demand for flexibility established and a potential supply and cost for each of the flexibility needs, we are then in a position to model how these various flexibility options would work together in meeting India's electricity supply needs. To understand which options will be used, we put together a series of supply curves for each flexibility need, mapping the cost competitiveness of each flexibility option in providing each flexibility need, as shared in a later section, Figures 4.1-4.4.

Power system models

An electricity system's flexibility needs connect independent and interlinked resources to meet overall system requirements. Using our supply curves and forecasts for annual hourly load shapes for Tamil Nadu, 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 Tamil Nadu 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, on flexibility from storage, on flexibility from 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



For the majority of our analysis, we have considered Tamil Nadu as a self-contained electricity system, ie, all of Tamil Nadu's electricity needs are met through the target renewable energy capacity, powerplant capacity either owned by the state or contracted from IPPs, NLC and NTPC, or through flexibility options, depending on the scenario, with no access to any exchange trading and any shortfalls met through backup capacity, in this case expensive diesel fired generation within the state. The reality however lies somewhere between this approach and a fully integrated system with no transmission and trading constraints with the rest of India, which would result in overall lower system costs for Tamil Nadu as well as India.

While these are no 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 on the last page.

2.5 Barriers

There are considerable barriers to development of flexibility resources and further, their adoption and integration once they are developed. 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 with which incentives. Gaps in data for individual powerplants makes it difficult to assess their potential, cost and trade-offs between different plants for flexibility.
- **Technology**. Advances or adoption of new technology will significantly help in meeting goals. With more flexibility options, metering, measurement, communication and settlement systems will be integral to monitoring, control, dispatch, incentivisation and planning. For example, to reduce the costs of storage and to create different types of storage systems that meet the various segments of the Indian electricity market.
- **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 producers need to become aware that these opportunities exist and that there is potential benefit from providing more 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 from providing their flexibility.
- **Incentives**. Incentives and markets need to operate at two levels, dispatch and optimisation as well as investment to align flexibility providers with overall 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 Tamil Nadu, including different teams at TANGEDCO, TNLDC, industry participants across generation, OEMs, smart systems, smart grids, demand response, batteries and storage systems and EV manufacturing and technology. We also reached out to industry groups such as CII, IESA and other organisations doing research in Tamil Nadu or more widely in India on related technologies and topics. These engagements helped us understand the institutional readiness to adapt to market reforms and the trade-offs in the context of Tamil Nadu. For our recommendations for Tamil Nadu, we also looked at successful international frameworks and projects, for example, case studies and interviews on battery storage systems across the US and Australia by our team at Stanford.

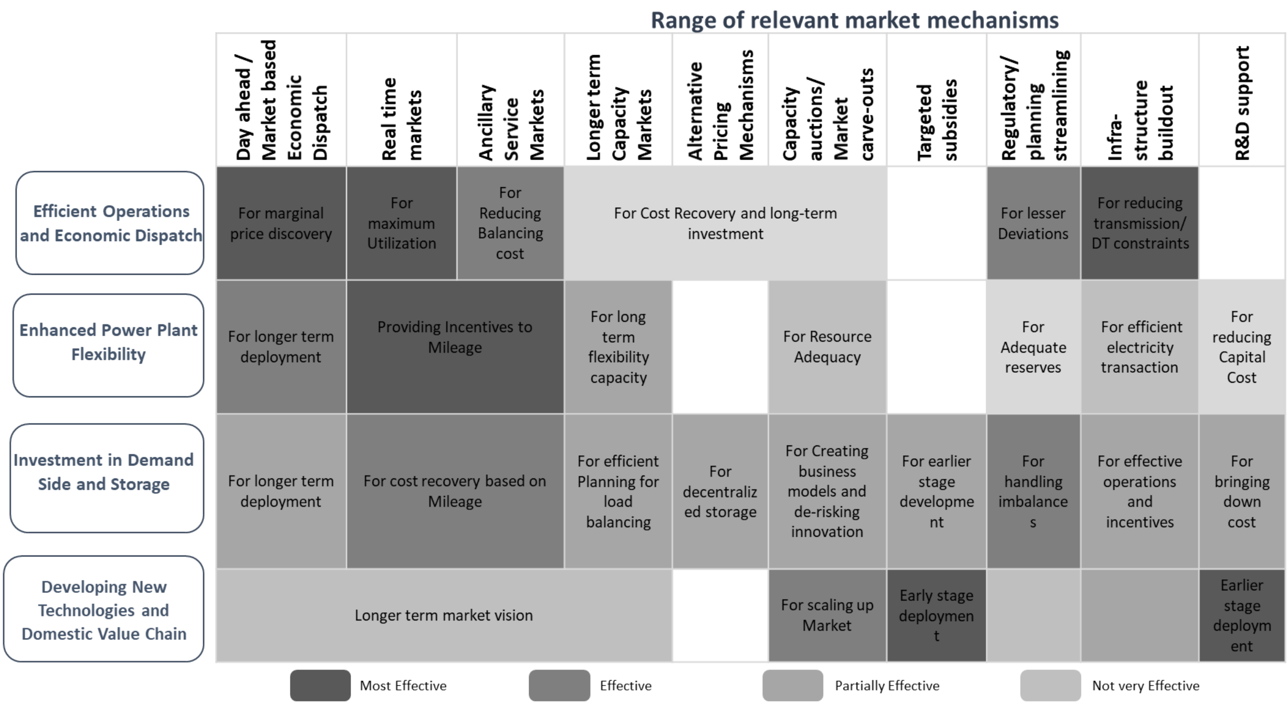
2.6 Role of market reforms

India can pursue ambitious renewable energy targets, but concerted action to overcome barriers is essential. Our analysis has also shown that flexibility reduces system costs and makes it cheaper to integrate more clean energy. Thus, increasing flexibility is a no-regrets steps for Tamil Nadu. While developing more flexibility should be addressed urgently to reduce costs and improve the quality of electricity supply, the pathway is not as straightforward. Tamil Nadu 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 structured to support old supply and demand models for electricity. Transitioning into the new behaviours, new market models and incentivizing evolution of operational and financing models will require not just the creation of new pathways. For example, markets can find the right price for ancillary and balancing services, real-time markets, market aggregators and deployment of control and measurement infrastructure to facilitate demand side flexibility. Assessment of approaches will also be required to integrate flexibility and flexible operation within the scope of existing contracts and arrangements (eg, adjustment of existing thermal generation contracts to compensate for financial and operational cost of flexible operations).

We evaluated a range of different market mechanisms (Figure 2.3) for Tamil Nadu to assess their application and effectiveness to break barriers and integrate priority flexibility options. On the basis of this analysis, we put forward our recommendations in Section 6 for a market reform and transition roadmap for Tamil Nadu, with steps to deliver greater flexibility in the near term (eg, expanding flexibility from thermal powerplants) and planning that needs to begin now (eg, pilots for storage, targeted procurement of flexibility from demand and storage), to create markets at a scale that reduces costs and provide incentives to integrate flexibility into the system.

Figure 2.3: Range of market mechanisms can be deployed to develop flexibility options and facilitate their integration into Tamil Nadu's electricity system



Source: CPI Energy Finance

3. Tamil Nadu's flexibility needs & challenges for market reform

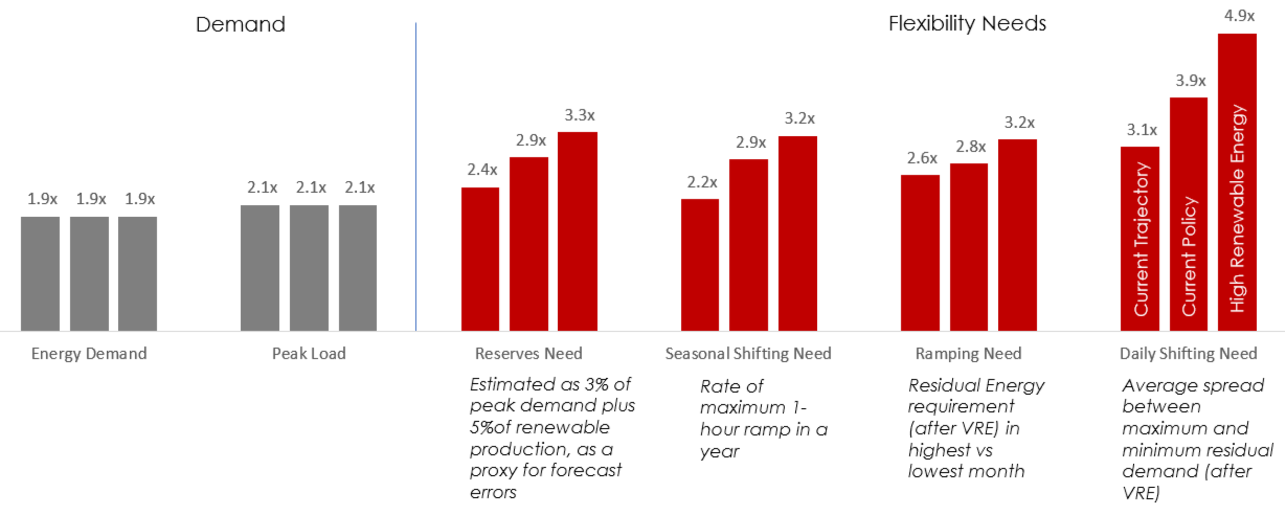
Tamil Nadu operates a diversified energy portfolio, with renewables contributing up to 50% of supply during monsoon season. As of December 2019, the state had installed 14GW of renewable capacity excluding hydro – 9.3GW of wind, 3.8GW of solar and 1GW of biomass.[8]

As India targets 175GW of RE capacity by 2022, Tamil Nadu is set to expand its wind and solar installations by 43%, with the largest additions coming from solar (8.9GW by 2022 and a further 9GW by 2023). By 2026/27, generation from c.42GW of installed renewable and nuclear capacity under the Current Policy Scenario, is expected to outstrip demand during the heavy monsoon season.

In the absence of additional flexibility and accompanying market reforms to facilitate and integrate flexible resources, Tamil Nadu faces the dual impact of curtailment of must-run renewables and compensating thermal generation for capacity not called, both of which have cost implications for TANGEDCO and electricity consumers.

Over the next 10 years, Tamil Nadu is expected to see a sharp escalation in daily balancing and ramping needs, driven by the rapid deployment of solar. By 2030, our analysis found that while demand and peak demand double, daily shifting needs grow more quickly, up to 4.9x under a high renewable scenario (Figure 3.1). Seasonal shifting needs see a more modest increase of 3.2x, even under the high renewable scenario.

Figure 3.1: Growth in Tamil Nadu's flexibility needs 2018-2030



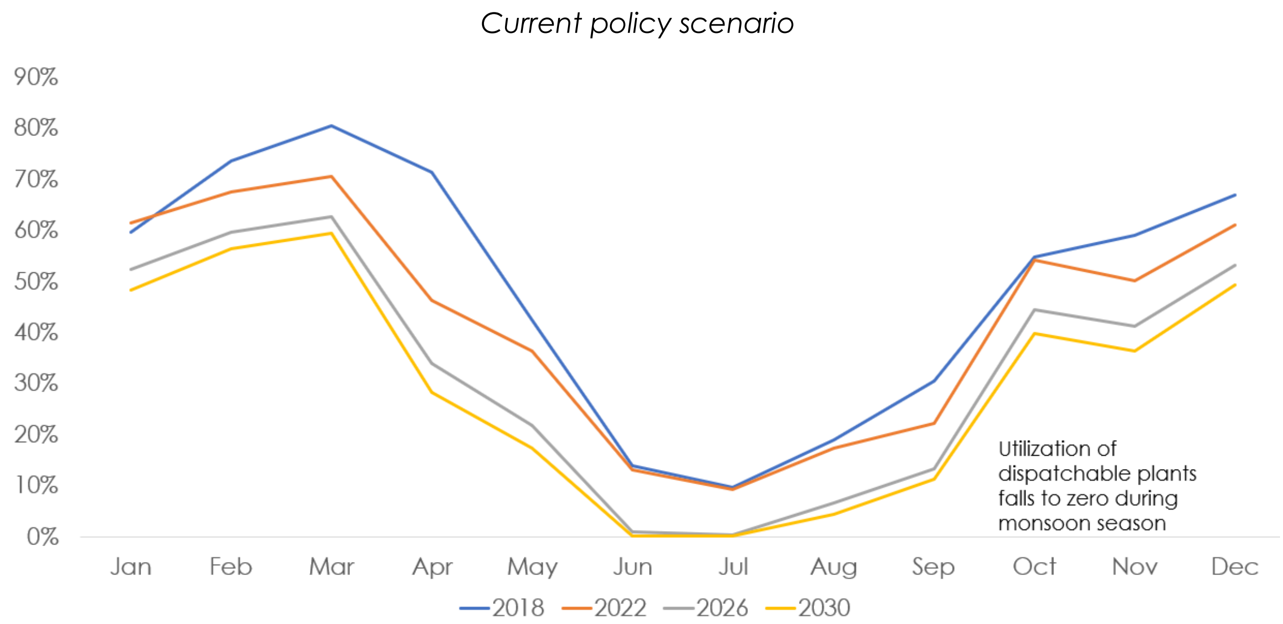
Source: CPI Energy Finance

In examining the challenges to Tamil Nadu's future flexibility needs we assessed the state's current and future energy demand, supply and flexibility resources. Tamil Nadu already manages the seasonal variation of its wind generation by coordinating maintenance schedules, where the majority of state-owned plants are brought offline for repairs during the monsoon season and output is reduced below the technical minimum of 70% load factor.

Our analysis shows that by 2026, residual load on the system will reach close to zero for days during the high wind monsoon season, requiring thermal generation assets to be turned off, as turning down the plants to minimum generation could still result in substantial excess energy that cannot be utilised within the state (figure 3.2).

[8] MNRE, 2019- https://mnre.gov.in/sites/default/files/uploads/StatewiseinstalledCapacityason31.12.2019

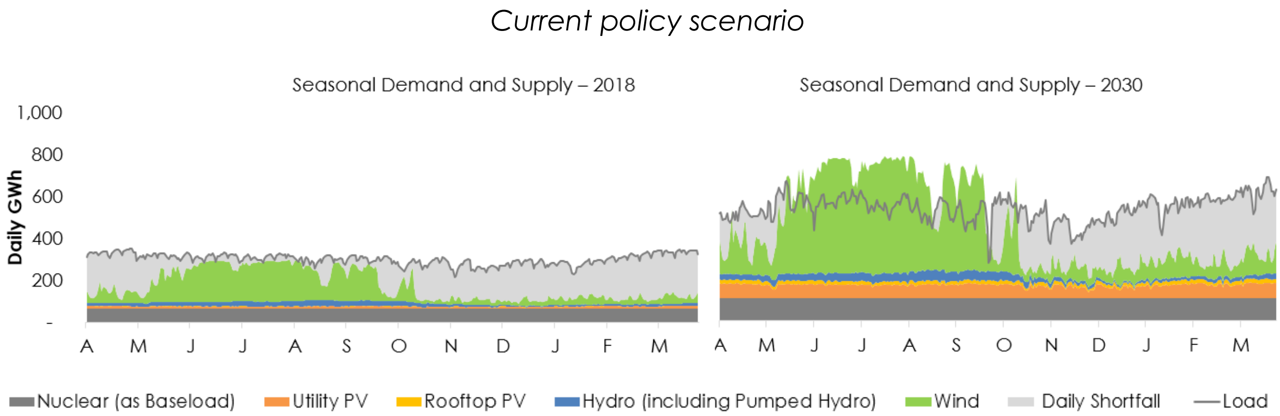
Figure 3.2: Monthly load factor of dispatchable plants – relative to peak net demand



Source: CPI Energy Finance

Over the next decade, this trajectory of increasing excess energy will continue, posing challenges for grid balancing and system costs during the monsoon season (see figure 3.3). At other times of the year, renewable generation alone will be insufficient to meet demand. In the absence of sufficient flexibility and integration measures, this growth has the potential to affect financing and investment costs for new resources in the state.

Figure 3.3: Growth in demand and supply

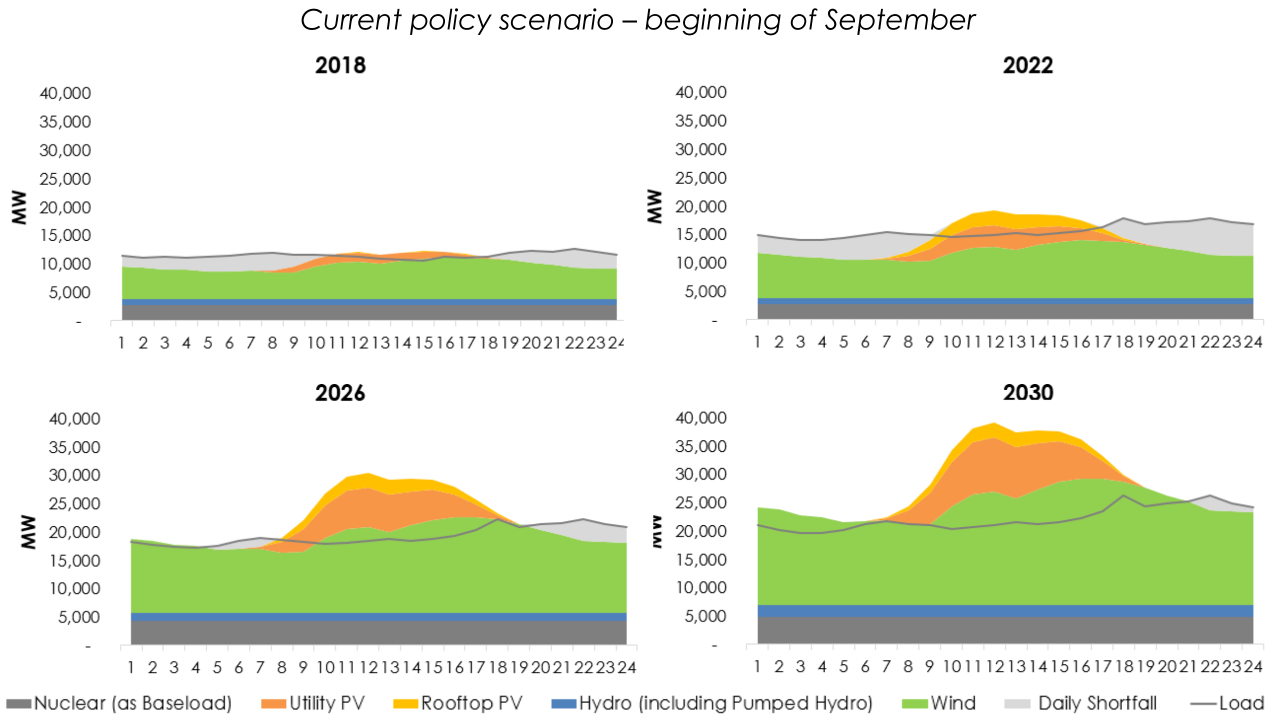


Source: CPI Energy Finance

We estimate that c.800MW of hydro capacity, split almost equally across reservoir-based hydro and pumped hydro is the primary flexibility resource for daily load management.

While daily shifting needs are manageable in the state today, we see a sharp increase in the daily balancing requirement by the middle of the next decade, largely driven by the addition of solar capacity (see figure 3.4) even under the most conservative conditions of the current policy scenario. Daily balancing need accelerates further under our HRE scenario. Mismatch of peak generation and demand will create excess energy while the sun is shining and leave shortfalls during peak demand periods, requiring ramping of alternative capacity as the sun goes down.

Figure 3.4: Growth of daily balancing needs



Source: CPI Energy Finance

Without measures to improve flexibility and integration, these increasing shares of wind and solar in the energy mix present the state's utility with a challenge to ensure energy security, self-sufficiency, reliability and resource adequacy over the next decade.

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

Furthermore, we found that Tamil Nadu's flexibility needs outpace those seen in India as a whole (see figure 3.5, on the next page). In the absence of any flexibility planning, renewable energy could be curtailed 15-20% and thermal generation would see strong variations in its annual load factors without any route to cost recovery. Therefore, market reforms to develop and integrate flexibility and improvements in transmission infrastructure to monetise country-wide variations in demand and supply of flexibility are essential over the next decade.

Figure 3.5: Flexibility needs will arrive sooner and be more significant in Tamil Nadu than India

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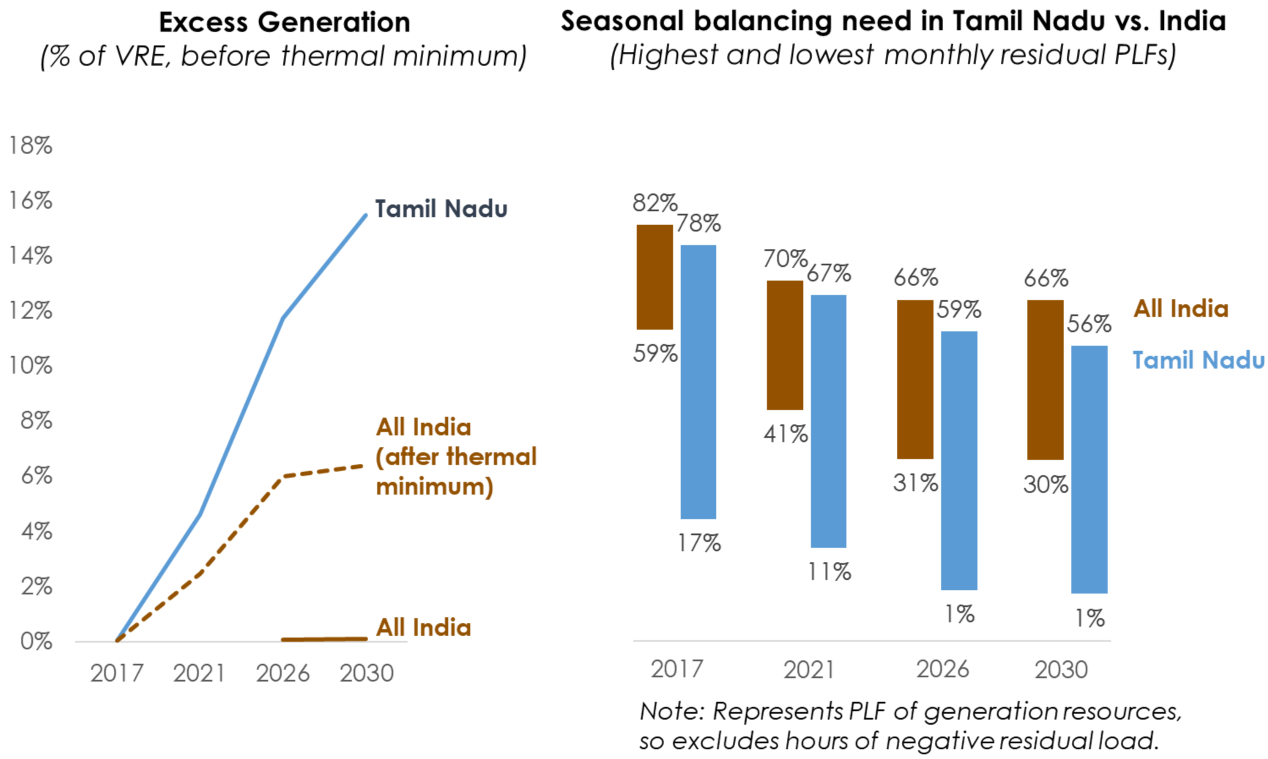


Source: CPI Energy Finance

4. Meeting Tamil Nadu's growing flexibility needs

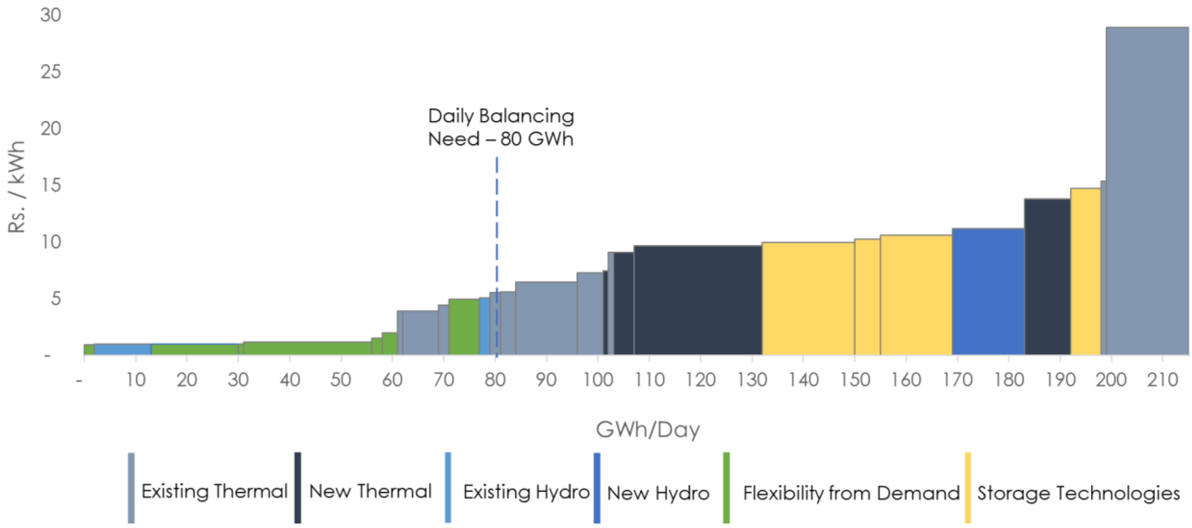
Tamil Nadu has many potential flexibility options that can be developed in time to meet its needs. Our analysis has focused on four main categories of resources:

- **Flexibility from demand.** Industrial, commercial, domestic and agricultural 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 help shift demand or supply, particularly for daily 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.** Neighbouring states, or even distant states if the transmission capacity is available, may have demand and generation profiles that are not correlated with Tamil Nadu's – and thus reduce overall flexibility needs – or have access to low cost demand or powerplant flexibility resources that can reduce overall system costs. Accessing interstate and national flexibility can provide value to Tamil Nadu and across India, as outlined in section 4.3, but will require further development of interstate markets and incentives.

This analysis focuses on the market reforms and flexibility development efforts that Tamil Nadu 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 Tamil Nadu and how that would evolve between now and 2030. We created supply curves for each flexibility need – 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. The figures on the following pages show how the mix of flexibility options compare with each other for different flexibility needs.

The first of these supply curves (Figure 4.1) shows the stacking of the options to provide daily balancing. With a potential supply of over 200GWh/day and demand of 80GWh/day by 2030, this flexibility need appears to be well covered. For daily balancing, flexibility from demand represents the cheapest option, however, existing hydro, existing and retrofit thermal powerplants also emerge as cost-competitive and viable options. If resources for flexibility from demand are not developed in time, greater volumes of thermal powerplants, including some of the new assets under construction also become viable options.

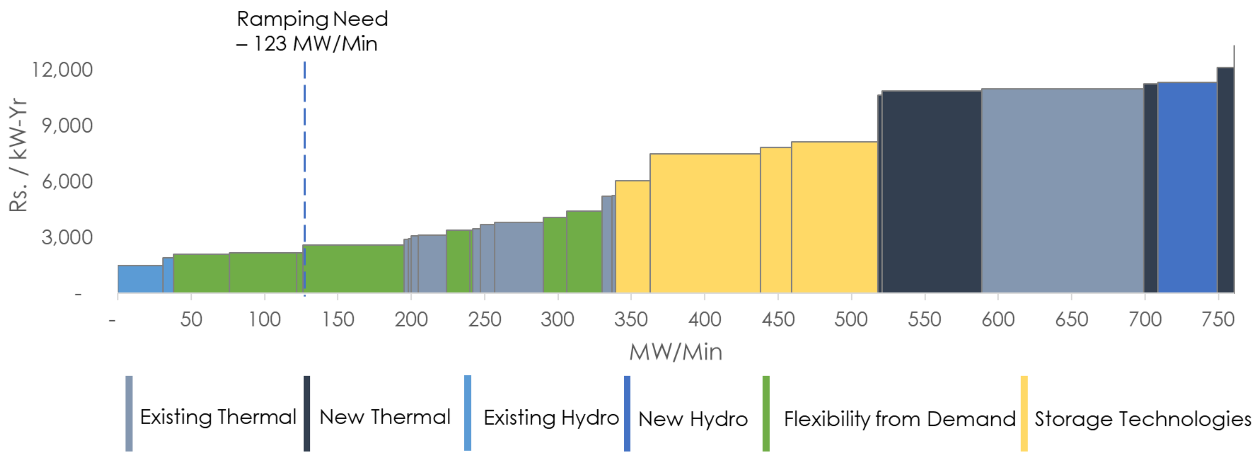
Figure 4.1 Supply curve for daily balancing for Tamil Nadu, 2030



Source: CPI Energy Finance

With the growth in solar in Tamil Nadu's energy mix by 2030, ramping requirements rise and the system requires more flexibility resources with fast response times. Existing hydro assets are the most cost-effective solutions but their scale is insufficient to meet all of the state's ramping needs (figure 4.2). Flexibility from demand can offer another low-cost option to meet ramping needs. But without these resources, the system will require more expensive thermal powerplants and storage resources.

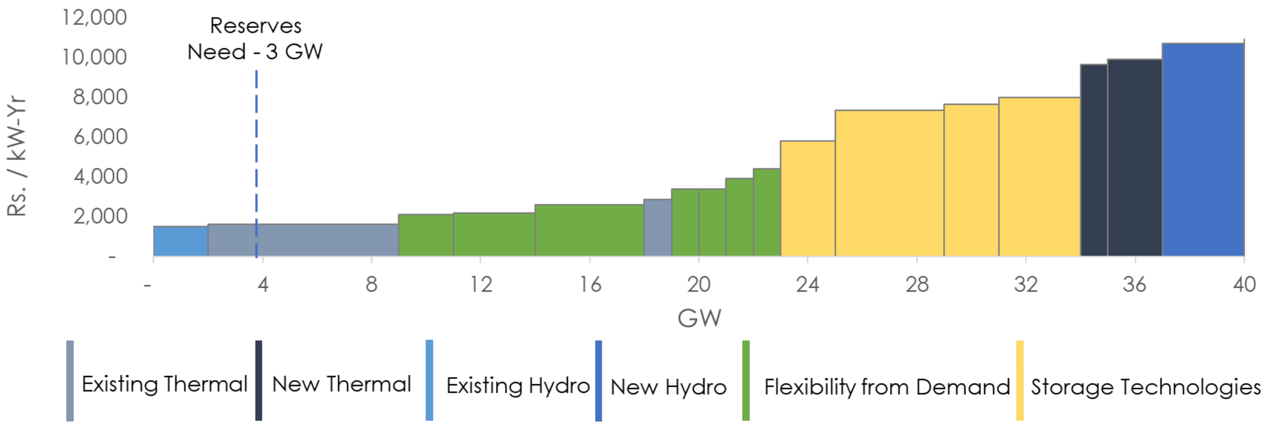
Figure 4.2 Supply curve for ramping for Tamil Nadu, 2030



Source: CPI Energy Finance

Tamil Nadu's reserve needs remain significantly low (~3GW) in 2030 and existing hydro and captive diesel based gensets can provide most reserve needs along with some resources for flexibility from demand, if the latter is excluded (Figure 4.3).

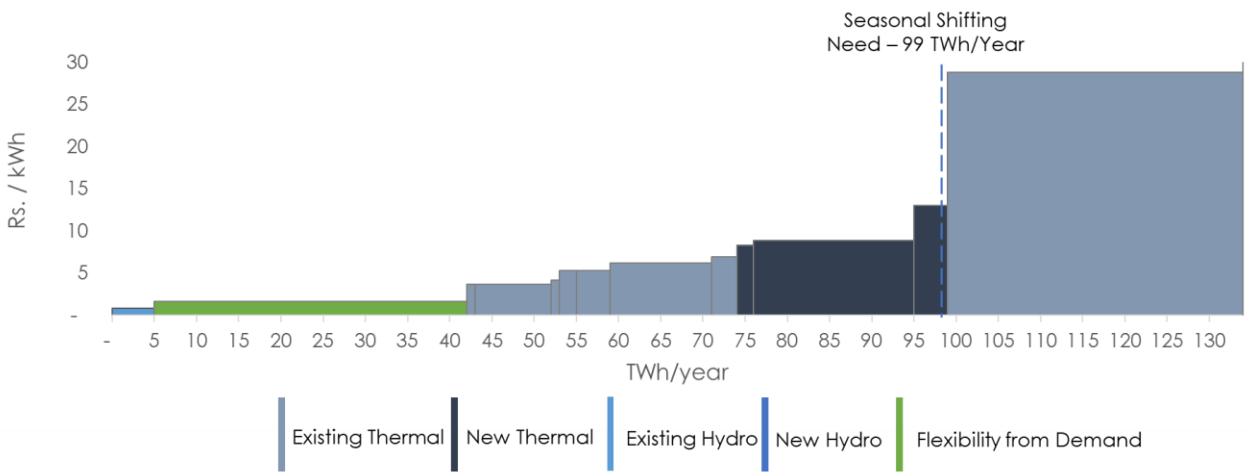
Figure 4.3 Supply curve for reserves for Tamil Nadu, 2030



Source: CPI Energy Finance

With the predominance of wind in Tamil Nadu's current resource mix, seasonal shifting requirements are the most pressing for the state. Tamil Nadu will need a targeted approach to integrate industrial partners for load shifting along with the exploitation of the full flexible capacity of powerplants to meet this need cost effectively (figure 4.4).

Figure 4.4 Supply curve for seasonal balancing for Tamil Nadu, 2030



Source: CPI Energy Finance

4.1 Impact of flexibility portfolios

In addition to these volume and cost assessments, our models enable us to assess the impact of each of the three resources on system cost, along with the need for curtailment (excess energy) and emissions. Of these three resources, flexibility from demand shows the most significant reduction in system costs across all renewable energy scenarios. However, developing all three options enables significant reductions in system cost and offers backup in case one or another of the options develops more slowly than forecast. Integrating these options to achieve the lowest cost and most reliable supply is an important task, both in balancing the development effort between options and developing systems that incentivise and dispatch these resources (Figure 4.5). Appropriate market signals – for development, investment, and dispatch of the options once available – will encourage the development of more options and the dispatch of options once developed.

Figure 4.5: Portfolio approach to flexibility delivers significant reductions in system costs along with highest optimisations in need for curtailment (excess energy) and CO2 emissions

Current Trajectory Scenario

	Excess Energy	System Cost	CO2
Base Case	4.7%	5.587 (Rs./KWh)	0.566 (t/MWh)
Fossil Flex	-9.4%	-9.9%	2.1%
Storage Flex	-66.4%	-9.3%	-2.7%
Demand Flex	-62.5%	-13.1%	-5.1%
Portfolio	-69.2%	-11.8%	-9.2%

Current Policy Scenario

	Excess Energy	System Cost	CO2
Base Case	13.6%	5.197	0.4370
Fossil Flex	-0.8%	-3.6%	2.3%
Storage Flex	-33.7%	-3.6%	-0.5%
Demand Flex	-33.0%	-7.9%	-3.7%
Portfolio	-45.5%	-5.6%	-7.8%

High Renewable Energy Scenario

	Excess Energy	System Cost	CO2
Base Case	22.2%	5.399 (Rs./KWh)	0.369 (t/MWh)
Fossil Flex	-6.7%	-0.8%	-5.9%
Storage Flex	-16.8%	-5.5%	-1.4%
Demand Flex	-20.9%	-8.7%	-8.4%
Portfolio	-33.2%	-7.1%	-13.6%

Source: CPI Energy Finance

For 2030, we assumed a base case without any market changes, flexibility development, action or planning. In this case, Tamil Nadu would meet its flexibility needs from powerplants operating as they do today, with no changes to minimum operating levels, start-up times, cost recovery for flexibility, etc. In each case, we estimate the economic cost of any load shedding or electricity shortfalls by assuming that captive diesel based gensets would make up the shortfall where necessary. The cost of meeting load shedding shortfalls without additional flexibility would constitute 11-22% 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.

To understand how flexibility will affect the cost and reliability of the Tamil Nadu electricity system, we modelled different sets of demand, storage and powerplant flexibility options against current and future load shapes and renewable energy outputs to simultaneously meet all electricity demand and flexibility needs, keeping the system in balance.

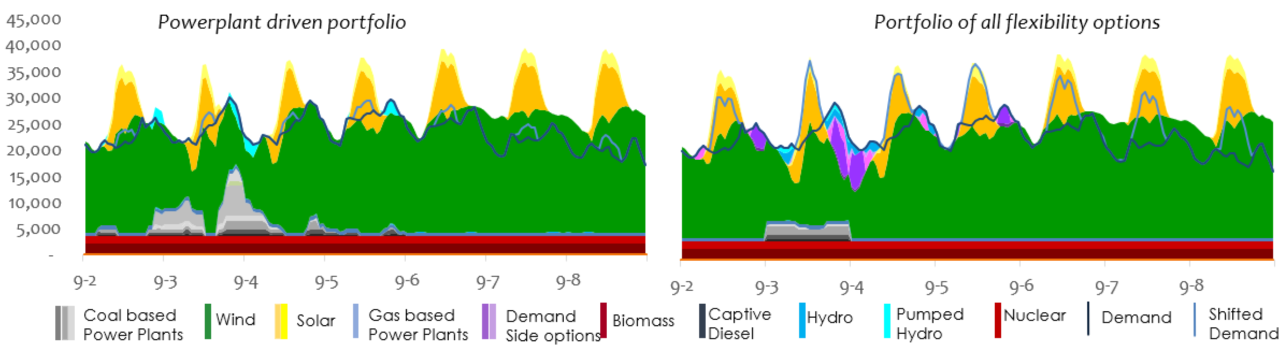
- **Powerplant driven portfolios**. System flexibility is provided entirely by thermal and hydro powerplants. Retiring plants are retrofitted (1.98GW) and new plants, already under-construction (3.4GW) or in the pipeline (4.8GW) are added.
  Across the three renewable energy scenarios, CTS sees the greatest savings in system costs with minimal impact under the HRE scenario, which has substantial excess generation, driven by technical, operational and economic interventions that allow coal plants to operate at technical minimums as low as 40% (55% for old state-owned plants). CO2 emissions rise across CTS and CPS scenarios as compared to the base case with the greater and more flexible utilization of thermal powerplants.
- **Storage driven portfolios**. System flexibility is provided by existing sources of flexibility combined with storage options. Thermal capacity addition is limited to plants already under construction or in the pipeline.
  Across the three renewable energy scenarios, storage significantly reduces the need for curtailment of wind and solar generation. Although storage costs will decline significantly by 2030, our estimates suggest that storage costs will nevertheless still be high relative to other sources of flexibility.
- **Portfolios driven by flexibility from demand**. System flexibility is provided by existing sources of flexibility combined with options for flexibility from demand. Thermal capacity addition is limited to plants already under construction or in the pipeline.
  Across the three renewable energy scenarios, flexibility from demand offers the most significant reductions in system costs, as this option is a load following resource which enables reduced generation from conventional resources (eg, coal) and also reduces overall emissions.

- **Portfolio of all options.** System flexibility is met with a combination of all options to determine which of them would be used, and at what scale, to offer maximum reductions in system cost along with the highest reliability of supply.
  Across the three renewable energy scenarios, the portfolio of all options offers the highest reductions in system costs, second only to flexibility from demand, along with the highest reduction for curtailment and emissions.

Below, we examine how the mix of generation and flexibility resources would fit together in two different weeks in 2030. Figure 4.6 looks at a week during the high wind monsoon season of September. In this sample week, generation from must-run capacity (nuclear, biomass, wind and solar) and minimum hydro exceeds demand during many hours of the day, with select hours showing need for generation from other sources. Thermal powerplants have PLF 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 dark blue line represents the pre-flexibility load that needs to be met across the week whereas the lighter blue line reflects the load after demand shifting. Note how in the left hand (powerplant only) there is a considerable amount of wind and solar energy above the grey 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 in some cases will need to be upgraded to turn on and off each day. On the right-hand side significantly 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 powerplants operate more continuously and only turn on when necessary.

Figure 4.6 Portfolio of flexibility options allow more efficient operation

Current policy scenario - a week with high renewable generation

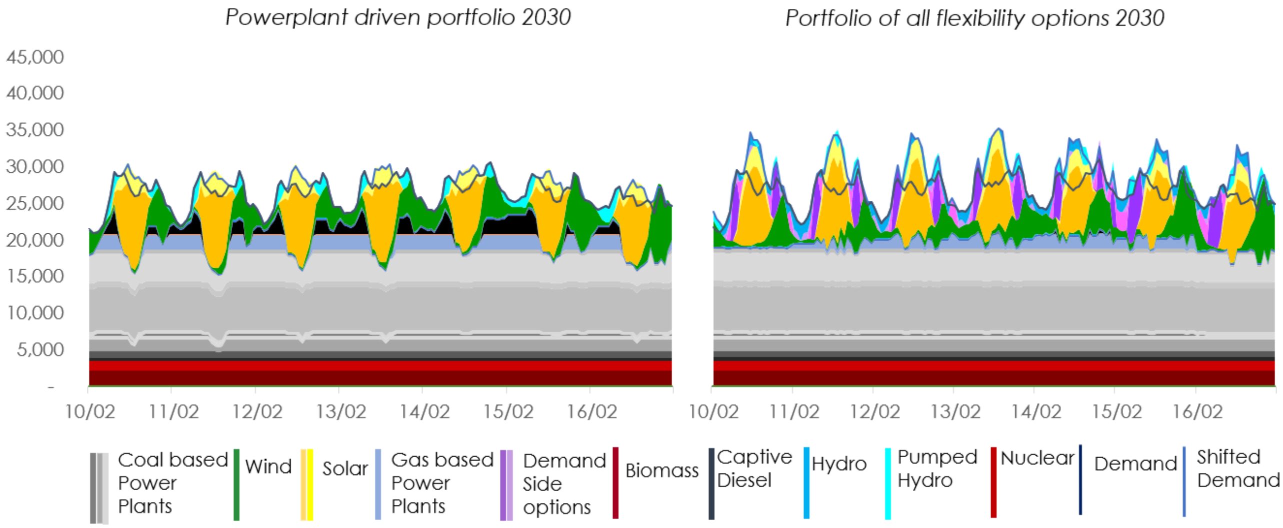


Source: CPI Energy Finance

Figure 4.7 looks at a week in the low wind season in February when generation from must run capacity is significantly reduced, requiring higher generation from powerplants – hydro as well as thermal. Note how in the left hand (powerplant only) there is high PLF required of thermal plants, including the need for back-up diesel genset capacity if we consider Tamil Nadu as a self-contained electricity system. We also note th30at 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.

Figure 4.7 Portfolio of flexibility options allow more efficient operation

Current policy scenario - a week with low renewable generation



Source: CPI Energy Finance

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

For our analysis, we further explored opportunities for reducing the thermal capacity addition for the state of Tamil Nadu. We assume that 3.4GW of coal-fired generation under construction is added to Tamil Nadu's portfolio across all scenarios. However, we ran additional scenarios for CPS and HRE, halving and fully eliminating the 4.8GW of pipeline capacity. Figure 4.8 below shows the impact. The costs in the base case increase marginally in both these modified scenarios, driven by the increase in the use of more expensive diesel gensets, assuming Tamil Nadu is a self-contained electricity system. However, as we add more flexibility across these scenarios, we see much higher savings in system costs, and similar trends in the need for curtailment and CO2 emissions reductions, as with coal pipeline scenarios. These results indicate that Tamil Nadu could decarbonize its electricity system more cheaply and more efficiently than policymakers may currently assume is economically and operationally feasible.

Figure 4.8 With higher renewable capacity, Tamil Nadu can look to reduce its coal pipeline

Current Trajectory Scenario - 100% Pipeline Coal Capacity	Excess Energy	System Cost	CO2
Base Case	4.7%	5.587 (Rs./KWh)	0.566 (t/MWh)
Fossil Flex	-9.4%	-9.9%	2.1%
Storage Flex	-66.4%	-9.3%	-2.7%
Demand Flex	-62.5%	-13.1%	-5.1%
Portfolio	-69.2%	-11.8%	-9.2%

Current Policy Scenario – 50% Pipeline Coal Capacity	Excess Energy	System Cost	CO2
Base Case	13.1%	5.587 (Rs./KWh)	0.423 (t/MWh)
Fossil Flex	-1.1%	-8.6%	2.6%
Storage Flex	-33.0%	-9.0%	-0.5%
Demand Flex	-31.9%	-13.8%	-2.8%
Portfolio	-43.8%	-13.0%	-7.1%

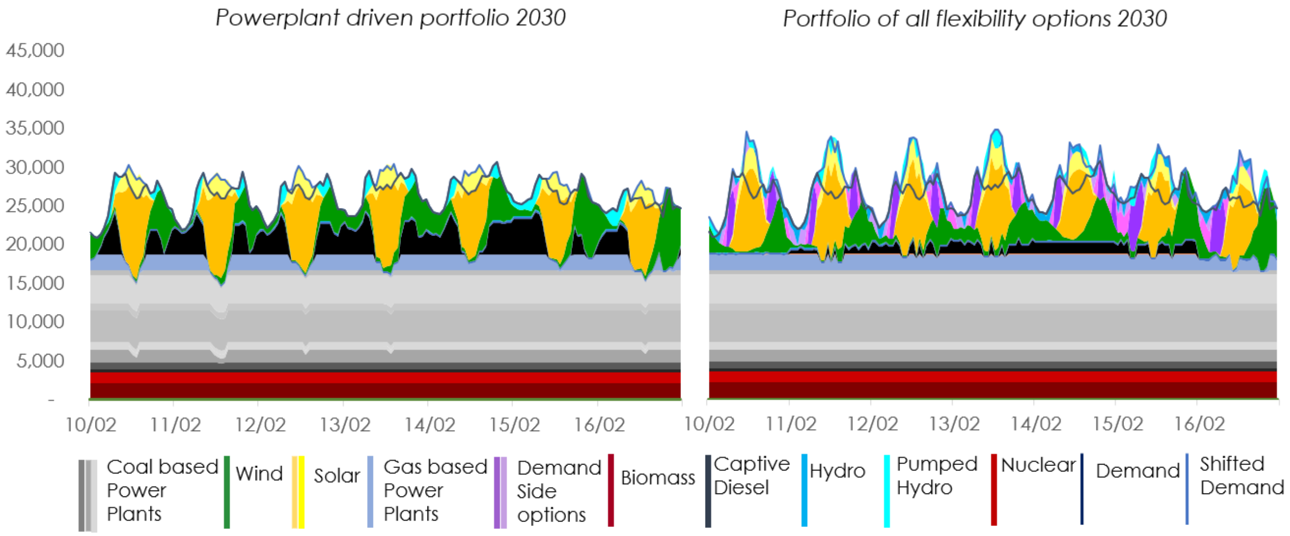
High RE Scenario – No Pipeline Coal Capacity	Excess Energy	System Cost	CO2
Base Case	20.9%	5.892 (Rs./KWh)	0.340 (t/MWh)
Fossil Flex	-0.8%	-9.7%	8.4%
Storage Flex	-14.2%	-12.9%	0.0%
Demand Flex	-16.9%	-18.2%	-5.7%
Portfolio	-27.3%	-17.0%	-9.5%

Source: CPI Energy Finance

In figure 4.9 below, we take a look again at the week during a low renewable generation season in February, under the modified CPS scenario. We can see the lower generation from coal as compared to figure 4.6. In the left-hand graph (powerplant only), the variability in the generation from coal-fired plants reduces but the need to access back up diesel increases during the low solar generation hours of the day. In contrast, on the right-hand side, thermal plants show almost no variability in their generation across the day and the need for back-up diesel gensets is much reduced even with 2.4GW less supply in the system, due to the shifting of both demand and supply.

Figure 4.9 Portfolio of flexibility options allow more efficient operation

Current policy scenario (with 50% of coal pipeline) - a week with low renewable generation



Source: CPI Energy Finance

4.3 Additional value for Tamil Nadu, interstate markets and transmission

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

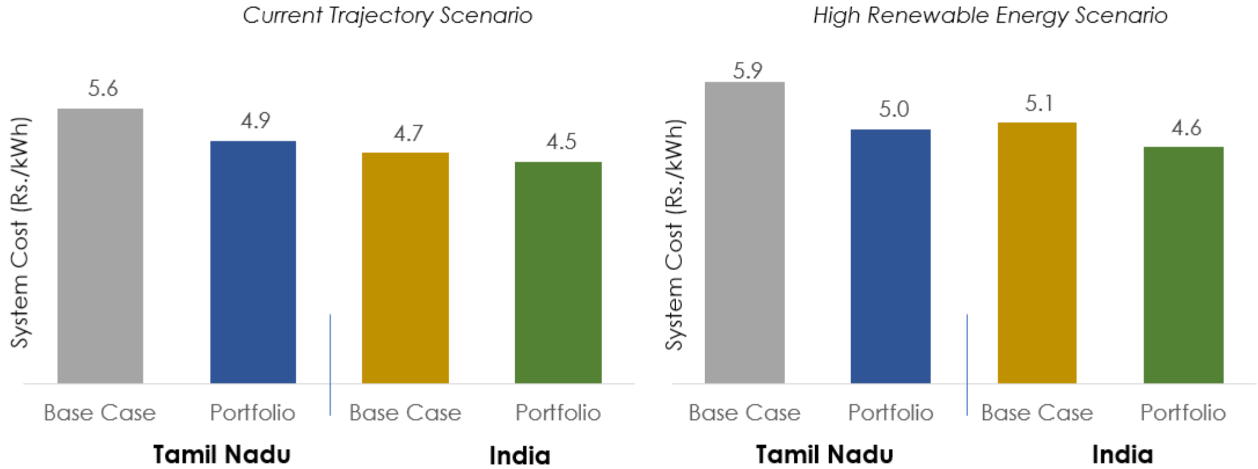
One crucial question is the extent to which increased interstate flexibility trading, national flexibility and electricity markets could provide the same flexibility at even lower costs. Developing precise estimates for the impact on Tamil Nadu would require similar analyses across each of the neighboring 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 have today. The result is 3-10% higher cost savings for the high renewable scenario with no coal pipeline, depending on the flexibility scenario.

One simplified way to estimate the potential of interstate flexibility markets on Tamil Nadu 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.[9] Figure 4.10 shows first that integration could provide significant value under both the CTS and HRE scenarios. Complete integrations would reduce system costs by a further 5-20%, without additional flexibility, depending upon the amount of renewable added to the system. Greater

[9] Developing a roadmap to a flexible, low-carbon Indian electricity system, March 2020 - https://www.climatepolicyinitiative.org/wp-content/uploads/2020/08/CPI-India-flexibility-25-August-2020-full-report-1.pdf

flexibility can be a partial substitute for greater integration, thus, with higher levels of flexibility the benefits of national integration fall to 7-9%.

Figure 4.10 Average system cost for electricity supply in Tamil Nadu and India, 2030



Source: CPI Energy Finance

Even complete integration is unlikely to provide all the benefits suggested by this comparison. Differential transmission losses could raise the cost in Tamil Nadu, regardless of the level of integrations, while transmission capex and system integration costs could further erode the benefits. Notwithstanding, there is likely to be significant further benefit from greater integration. Nevertheless, the analysis also suggests that markets at the state level in Tamil Nadu 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 Tamil Nadu 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 Tamil Nadu 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 Tamil Nadu'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 Tamil Nadu'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.

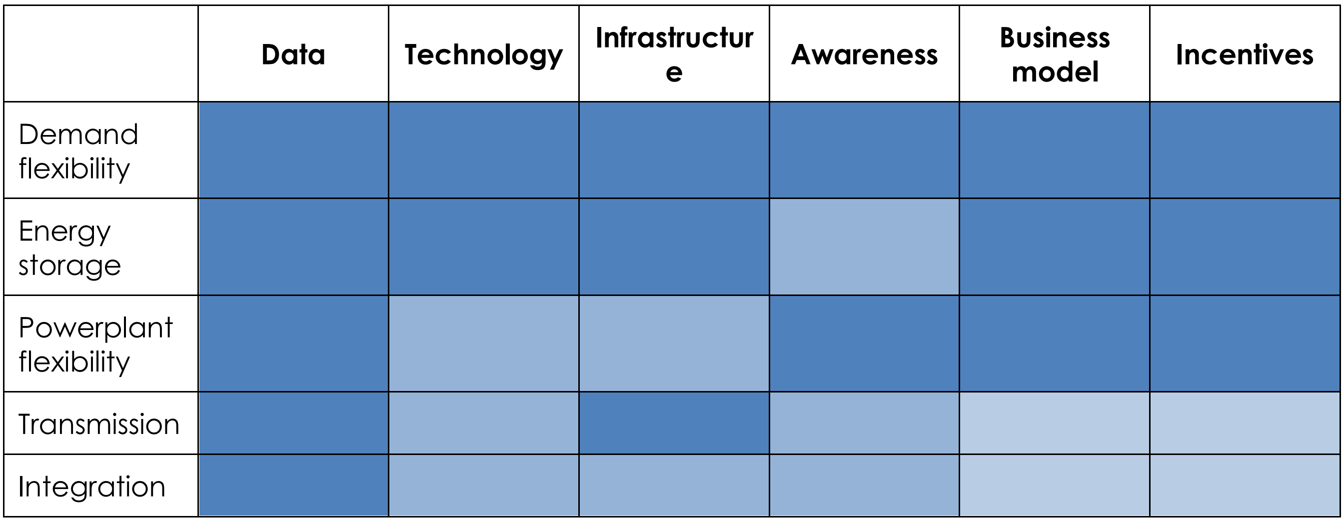
Some transitions can be targeted immediately whereas others will need to be planned for with policy interventions that can pave the way for the resources, investments and discovery of business models to deliver the flexibility options for when they are most urgent and needed by Tamil Nadu.

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 Energy Finance

5.1 Meeting Tamil Nadu's flexibility needs from demand

We set out in the previous chapter that demand flexibility represents the most scalable and cost-effective resource. However, demand flexibility is not just one resource, but a series of resources, which partly explains its ability to scale and impact on cost.

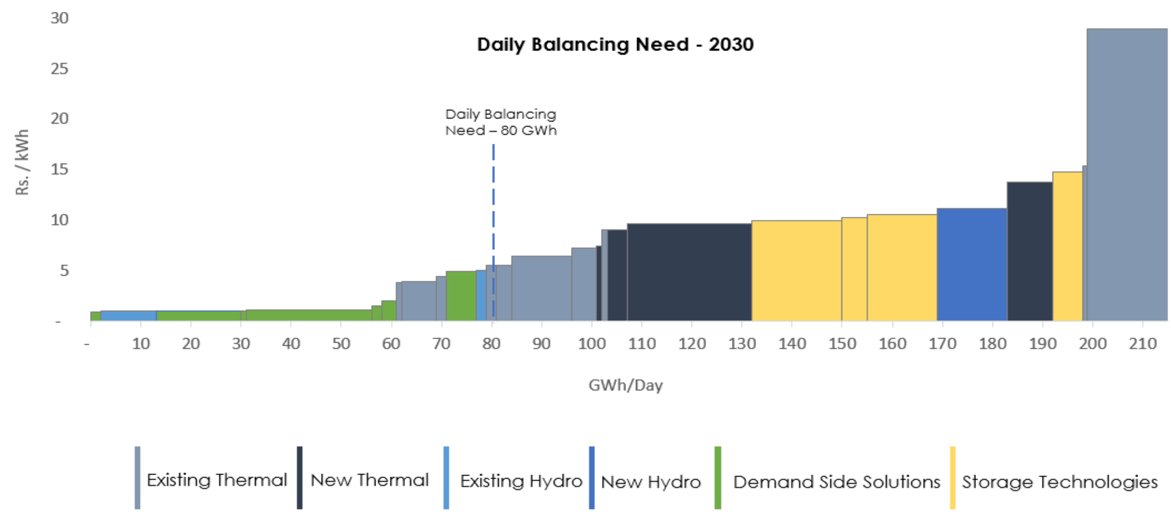
In Tamil Nadu today, agricultural pumping, space cooling and industry are the primary sources of flexibility considered, while EV charging is expected to be a significant addition in the future especially as the state's EV fleet expands. Existing captive diesel generation can help meet daily balancing needs when demand exceeds supply.

We estimate that 10GW of demand that can be used flexibly today, a figure that we forecast could more than double to 23GW by 2030 from:

- **EV charging** presents one of the cheapest forms of flexibility across many balancing needs, but its development requires new business models, charging infrastructure and incentives with real time pricing.
- **Agricultural pumping** represents 15%[10] of demand in Tamil Nadu and flexible operation of pumping provides another low-cost opportunity, but one that requires separation of agricultural feeders, new metering, control systems, pricing schemes and incentives.
- **Space cooling** has a high potential for flexibility applications such as reserves and ramping. However, this segment requires specifically designed incentives and metering to stimulate behaviour change.
- **Industry** consumes 30-45% of Tamil Nadu's electricity supply and provides a low-cost option for seasonal load shifting by improving incentives to manage maintenance periods or production schedules.

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

Figure 5.2 Potential for daily balancing from demand flexibility in Tamil Nadu 2030



Source: CPI Energy Finance

5.1.1 POTENTIAL FOR FLEXIBILITY FROM DEMAND FOR TAMIL NADU

Load shedding, forcing involuntary participation of consumers in providing flexibility from demand has been a widespread feature of India's power system to manage peak demand, supply shortfalls and outages. But this option led to a significant rise in the private ownership of

[10] SRPC Annual Report 2019

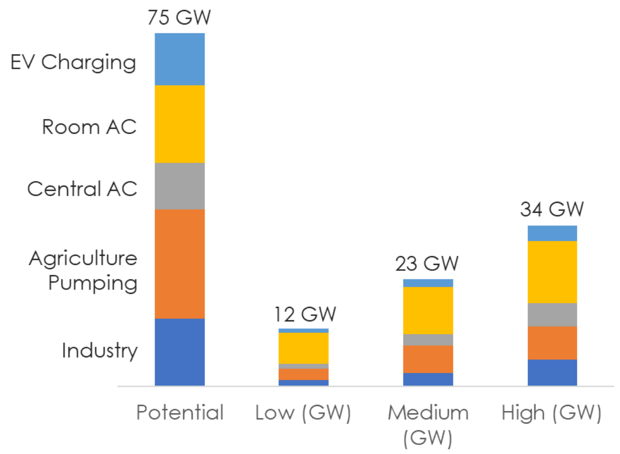
expensive diesel generation as back-up to maintain productivity. More recently, planned load shedding or scheduled maintenance has increased productivity and improved power quality.

Encouraging consumers to participate providing flexibility from demand requires clear incentives, investment in infrastructure and policy interventions to create the market structures, intermediaries and monitoring and billing systems that allow consumers to optimize their participation.

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.

We forecast that peak demand for these resources will represent around 67GW by 2030, of which we estimate that between 12GW and 34GW could be used flexibly (see figure 5.3 below). Agricultural pumping and EV charging make the largest contribution to daily shifting needs, while none of these resources would play a role in seasonal shifting, the exception being shifting between seasons for industrial loads.

Figure 5.3 Potential for flexibility from demand in Tamil Nadu by 2030



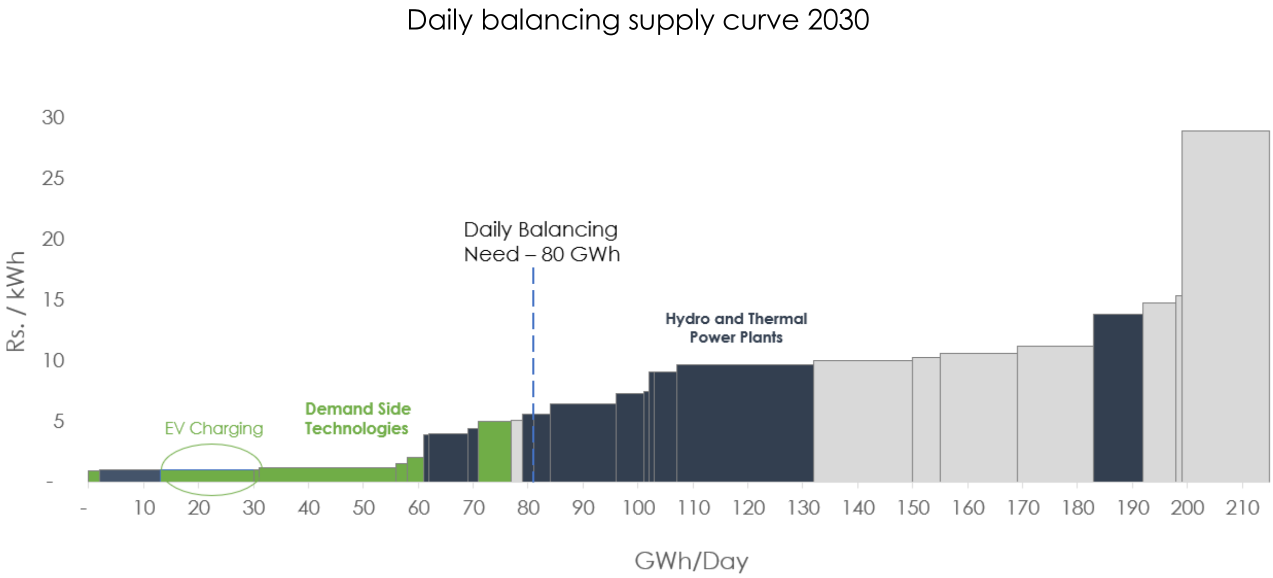
2030 Flexibility	Operating Reserves (MW)	Ramping Flexibility (MW/Hr)	Daily Flexibility (MWh/Day)	Seasonal Flexibility (GWh/Year)
Industry	1,427	1,427	2,854	
Room AC	2,306	2,306	2,306	
Central AC	985	985	1,970	
Agriculture Pumping	4,108	4,108	24,649	
EV Charging	2,997	2,997	17,985	

Source: CPI Energy Finance

5.1.2 FLEXIBLE CAPACITY FROM ELECTRIC VEHICLES

Electric vehicles (EV) offer an attractive source of flexibility to the grid and despite the high costs of batteries which we will explore in the next chapter, this resource is worth pursuing as we see its potential to provide one of the cheapest forms of demand flexibility. It also has the potential to help smooth out the evening peak demand. Without intervention, demand for charging EVs may further intensify pressure on the grid at the end of the day.

Figure 5.4: EV charging could be one of the cheapest options for demand flexibility



Source: CPI Energy Finance

Ideally, electric vehicles could be connected to allow two-way flow of electricity; the batteries could be charged when electricity supply was plentiful, and the batteries would feed back to the grid when supply was short. While this vehicle to grid (VTG) application is attractive, in Tamil Nadu, as elsewhere, this potential 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 payments systems. However, even falling short of full VTG, there remain many attractive options to provide flexibility by shifting when batteries are charged, even if they cannot supply energy back to the grid. We estimate up to 6GWh of daily energy shifting potential in Tamil Nadu in light duty vehicles (LDV) alone (see table 5.1), which represents almost 8% of Tamil Nadu's peak daily balancing needs in 2030. Inclusion of busses and trucks could increase this potential substantially.

Adjusting the timing of battery 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, eg, connection, metering, and incentives. For example, increasing flexibility might require the installation of higher speed charging, but no new battery costs. However, there are numerous behavioural, incentive, and logistical issues to overcome. These issues depend on the vehicle itself and how the vehicle is used, and the mechanism used for charging the vehicle. 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, Tamil Nadu may be able to simultaneously lower the cost of electricity supply while lowering the total cost of transport using electric vehicles.

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 analysis from the vehicle manufacturer Mahindra and the debt ratings agency CRISIL.[11]

[11] CRISIL report on Electric Vehicles - https://www.crisil.com/content/dam/crisil/our-analysis/reports/Research/documents/2020/02/getting-charged.pdf

Table 5.1. EV electricity demand and consumption 2030

EV Segment	Vehicles ('000)		Demand (MW)		Energy (GWh/day)	
	2019 (est)	2030 (est)	2019 (est)	2030 (est)	2019 (est)	2030 (est)
Three Wheel (E3W)	63.0	1169.7	394	7311	0.3	5.8
Two Wheel (E2W)	12.6	66.6	79	417	0.0	0.2
Four Wheel (E4W)	0.5	1.0	9	18	0.0	0.0
Total	**76**	**1237**	**482**	**7745**	**0**	**6**

Source: CRISIL report, CPI Energy Finance

- The three-wheel segment (E3W) would contribute the vast majority of the market and flexibility potential as we see the largest growth in this market segment to replace the existing three-wheeled vehicles, especially if there are incentives to drive uptake to help reduce local air pollution;
- The two-wheel segment (E2W) consists of motorbikes that are either privately owned for personal use or used by couriers for deliveries. Vehicles owned privately for personal use are typically more difficult to access for flexibility as the transaction costs associated with identifying and managing individual accounts are high, especially compared to the potential value of flexibility per vehicle, which is small given the low consumption.
- The four-wheel segment (E4W) is also typically privately owned and, despite the larger consumption, can be similarly difficult to access economically for flexibility. One option is fast chargers with time of use pricing, but this option is unlikely to have a major impact before 2030, although circumstances can change quickly, as they have with rapid expansion of EVs for personal use and taxis in China, so maintaining a watching brief is advisable. EV fleets are a different case, as charging can be aggregated, but only a very small proportion of potential flexibility comes from this segment. Again, maintaining a watching brief or prompting flexibility friendly versions of EV uptake is advisable.

Potential flexibility from EVs depends on the usage and behavioural characteristics of E3W users, but, significantly, also the design of the charging infrastructure, which Tamil Nadu can influence. In Tamil Nadu, three wheelers are used mostly as taxis. As a result, the vehicles are used primarily during the day or evening and would likely be charged at night. In fact, without intervention, it is possible or likely that E3Ws will be plugged in at the end of the day, adding to ramping requirements after sunset. Provision of flexibility depends critically on the system used for charging. We explore 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, and,
- **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 E3W batteries are relatively small, at an average of 5kWh, 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 E3W vehicles will primarily be used during the day, 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 600MW of evening peak and create 1GWh/day of daily load shifting, between 15% and 20% of the EV potential. This method of shifting is likely to cost between 2 - 3 Rs/kWh, given the capital costs of the chargers and the incentive and billing systems required.

Battery swapping: The alternative to charging batteries while the E3W is 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 E3Ws. In fact, this process is already in use with lead acid batteries.

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, TANGEDCO, 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, Tamil Nadu could access 80-100% of the EV flexibility potential, roughly six times that of the battery-in-vehicle model. We estimate that the cost of this model 1.5- 2 Rs/ kWh which is 20% cheaper than the battery-in-vehicle model.

5.1.3 FLEXIBLE CAPACITY FROM AGRICULTURE PUMPING

Agricultural pumping represents about a fifth of the electricity demand in Tamil Nadu. Most of this supply is either free of charge or highly subsidised to support farming, which accounts over a fifth of the state’s GDP. Our analysis found that at the current rate of growth, the number of pumps used in Tamil Nadu for agriculture would rise by over 40% in the coming decade, with a similar rise in electricity consumption from agricultural pumps despite improvements in energy efficiency.

Table 5.2: Growth of agricultural pumping sets to 2030

	2018	2030
No of grid connected pump sets	2,166, 453	3,088,843

Energy consumed by pump sets (BU) *(5HP pumpset, running 4.36 hrs /day)*	18	26

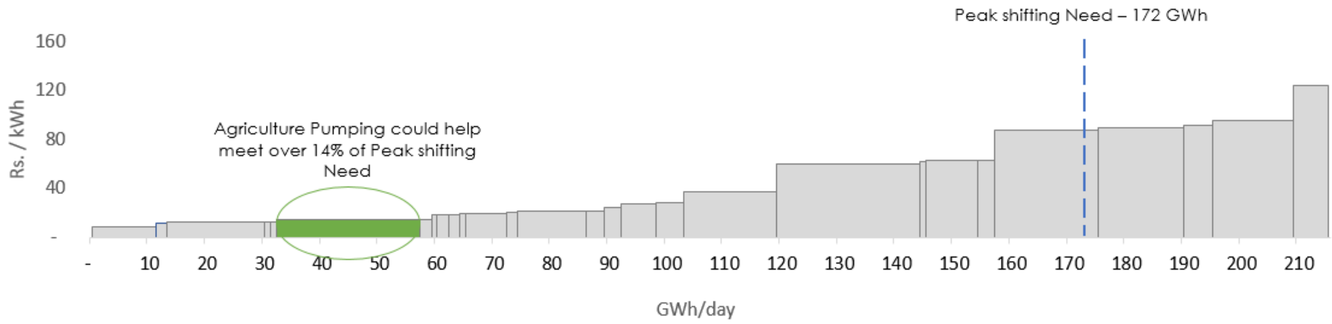
Source: TNEB Statistics, 2018, CPI Energy Finance

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 hence this load has the potential to be moved across the day. But its use as a demand flexibility resource requires detailed attention from policymakers, as well as incentives for end users and investment in new infrastructure to install pumps that are separated from domestic water supply for farmers.

Our analysis shows that by 2030, agriculture could account for almost 26TWh of electricity consumption. Without any intervention and incentives, this demand is expected to be spread across the day, with at least some of the load overlapping with periods of peak generation. Even if 25% of this load were shifted, TANGEDCO would benefit from c.24GWh of daily energy shifting potential which represents 12%-18% of Tamil Nadu's peak balancing needs in 2030 (see figure 5.5 below).

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

Peak balancing supply curve 2030

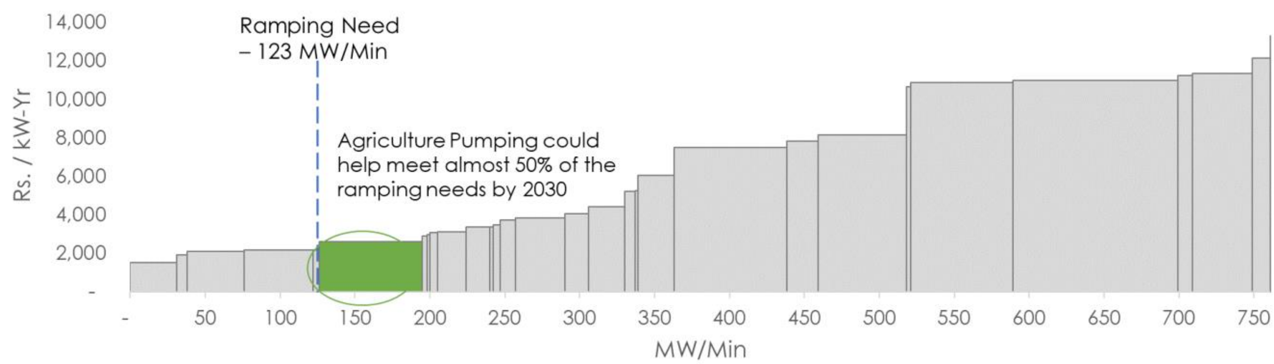


Source: CPI Energy Finance

Agriculture pumping is also a marginal resource for ramping, with capacity to meet almost 50% of Tamil Nadu's ramping needs (figure 5.6). 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 can play a significant role in meeting Tamil Nadu's ramping requirement by 2030

Ramping supply curve 2030



Source: CPI Energy Finance

In order to provide flexibility through agricultural pumping, it is imperative that only the consumption of the pump sets is shifted without disruption to the supply to rural households and industries. To accomplish this, agricultural pumps would need to be connected to a separate feeder which can be turned off during periods of high demand and turned on during periods of excess wind and solar generation each day.

In order to allow this freedom and to minimize T&D losses, a feeder segregation programme is currently underway in India 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 reduce the cost of peak power procurement;
- Improve quality of supply in non-agricultural segments.

The cost of setting up an additional feeder is typically between INR 2-2.5 lacs per kilometre, translating into a cost of c.INR65,000 per connection. The central government has committed budgetary support for the feeder separation and strengthening of the sub-transmission and distribution infrastructure in rural areas. Feeder separation programmes have been successfully completed in Gujarat, Andhra Pradesh, Punjab, Rajasthan, Haryana and Madhya Pradesh, among other states. However, Tamil Nadu is yet to embark on its own programme.

Data from Gujarat show that load curves from the state have flattened, with the discoms being able to shift pumping demand to off-peak hours. The state registered a growth of 10.39%, in energy input, from FY 2007-08 to FY 2009-10. However, peak demand grew by only 1.93% during the same period along with marked reduction in the power outages and voltage related issues.

Segregation of the feeders also allowed the disaggregation of the agricultural power consumption from broader rural load, significantly reducing the volume of electricity supply to agriculture. Additionally, agriculture pumping can provide a cost-effective option for not just meeting peak and daily shifting needs but also of ramping, where agricultural load could be ramped down at the same time that RE generation starts to taper, to reduce the additional ramping load burden on the system.

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 Tamil Nadu 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 resource.

5.1.4 FLEXIBLE CAPACITY FROM SPACE COOLING

Tamil Nadu has large potential for a space cooling driven by current low penetration of air conditioning (~14%)[12] which is expected to rise to 70% by 2040, in line with the penetration expectations for India, driven in equal parts by more frequent cooling degree days and greater affordability thanks to increases in household income.

In parts of Tamil Nadu where AC penetration is already high, such as Chennai, cooling already accounts for 40%-60% of summer peak load.

Shifting AC cooling by a few minutes for room ACs or precooling using the chiller for central ACs would provide flexibility to the electricity system. Changing the target temperatures on the thermostat also reduces pressure from cooling load providing additional sources of flexibility from both residential and commercial consumers.

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

5.1.5 RESIDENTIAL AIR CONDITIONING

Our research showed that room ACs account for almost 60% of all cooling capacity and their share in the cooling mix has increased in recent years. Our estimates suggest that there are currently 3.9 million room air conditioners installed in Tamil Nadu and nearly half a million room air conditioners being sold in the state each year, with a sales CAGR of 11.5%

Of these, nearly 50% of the AC sales go towards new installations. By 2030, the number of installed room air conditioners is expected to reach 16.1 million units with a combined cooling capacity of 23.1 million tons[13]. Energy efficiency is also improving – our analysis shows that electricity consumption by an average air conditioner is expected to halve by 2030. Even factoring in this energy efficiency benefit, the load from room ACs is expected to almost triple to 2030.

Table 5.3 Potential for flexibility from residential air conditioning projections

No of room air conditioners as of 2017	3,901,669
Expected growth rate	11.5%
Expected no of room air conditioners by 2030	16,126,899
Power consumption p.a. for a 1.5ton AC (approx.) (kWh)	1096.6
Connected load (GW) - 2030	23.06
Flexibility potential as % of total connected load (GW)	10-25%

Source: Motilal Oswal, 2018, CPI Energy Finance

Even if a small percentage of this load can be harnessed for flexibility, it would add significantly to flexibility potential from demand response. 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, air conditioners would need to be connected to smart systems which could temporarily reduce their electricity consumption during peak periods. 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.

5.1.6 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[14]. The connected load from central ACs in Tamil Nadu is expected to double by 2030 from 4.7GW to nearly 9.8GW. Office complexes are expected to be the largest consumers of central air conditioning capacity. It is easier to implement flexibility options such as thermal storage with central ACs as a substantial load is controlled from one point.

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[13] A ton is the cooling capacity of an air conditioning system. One ton is equal to the amount of heat required (288,000 Btu) to melt one ton of ice in a 24-hour period. The cooling capacity of an AC is based on its rating.

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

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.

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

5.1.7 FLEXIBLE CAPACITY FROM INDUSTRY

Industry accounts for 30-45% of electricity demand in Tamil Nadu, depending on the time of year, and should therefore be pursued to maximise the efficiency of the system and lower costs[15]. However, the industrial sector is very diverse, with some industries operating energy intensive processes that run nearly around the clock, while others have more variable loads. In addition, the costs 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.

In Tamil Nadu, textiles represent about 25% of industrial demand, while cement and steel and iron represent just under 10% each[15]. Estimates suggest that, depending on the industry, between 5%-14% of a consumer's demand would be available for daily shifting, with additional potential available with greater investment and innovation. Significantly, the largest sector, textiles, is at the highest end of the estimates. A full understanding of the flexibility potential of industry in Tamil Nadu 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. The size of the potential opportunity should make this a priority.

While effective market design and price signals and large-scale consumer engagement are the keys to unlocking the full flexibility potential of industrial demand, there are at least two areas that offer more immediate access to flexibility potential: captive generation and seasonal flexibility.

5.1.8 INDUSTRIAL FLEXIBILITY FROM CAPTIVE GENERATION

Large industrial consumers with captive powerplants represent about 40% of industrial demand in Tamil Nadu. These consumers meet just over one half of their total electricity demand through self-generation and export a further 10% of their net generation back to the grid. The vast majority of this self-generation uses coal or gas, with some diesel and renewable energy on the margins. The captive generators operate at load factors of around 50%, indicating that they operate flexibly and could have the potential to shift their operation further with the appropriate incentives. Our estimates, based on data available from CEA's 2018 general review reveal an installed captive capacity of over 4GW, with average utilisation of c.25GWh/day – even a fraction of this capacity could play an important role in managing Tamil Nadu'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

[15] General Review – 2018 – Central Electricity Authority

not reflect the value of the energy to TANGEDCO and Tamil Nadu's electricity system, 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 40% of industrial load is driven by these large 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 40% of all industrial demand and improve the flexibility of the captive generation itself.

5.1.9 SEASONAL INDUSTRIAL FLEXIBILITY

The second more immediate industrial flexibility option for large consumers revolves around seasonal flexibility. For most of India, our analysis shows that seasonal flexibility issues do not become of major importance for another 5-10 years, although we suggest developing flexibility measures to reduce costs and get ahead of the timing. In Tamil Nadu, however, seasonal issues are more severe given the prevalence of wind energy with output driven by the monsoon season. 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. 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.

5.1.10 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.

5.1.11 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.

Tamil Nadu has great potential to expand the availability of demand flexibility, from 10GW today, to 23GW, an maybe even 34GW by 2030. Most of that demand flexibility capacity can be developed as a very low-cost resource. But in order to achieve that almost tripling of low-cost demand flexibility, the state will need to tap into primary sources of flexibility existing today existing sources 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 demand flexibility.

If the state starts to address some of the barriers to scaling up demand flexibility now, the outcomes from those actions today will have maximum impact in the future. The main areas that Tamil Nadu's policymakers and TANGEDCO 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 demand flexibility structure is built out in Tamil Nadu.

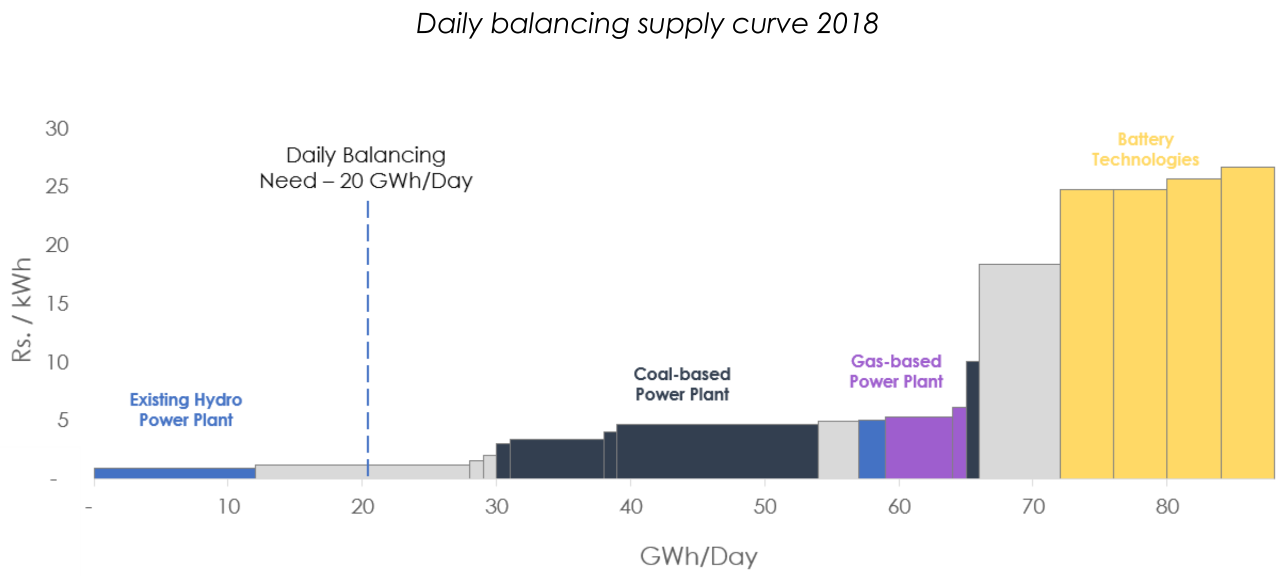
5.2 Meeting Tamil Nadu's flexibility needs using storage technologies

Energy storage is expected to play an essential but limited role in the short term in integrating Tamil Nadu's growing supply of intermittent renewables. Our analysis has shown that although there are two potential sources of storage in the state – existing resources from hydro capacity and emerging technologies such as battery storage – scale for both resources is limited, albeit by very different factors.

Today, Tamil Nadu has enough flexible hydro capacity to meet storage demand, but it will soon require additional means of energy storage beyond its current hydro assets and pipeline over the next decade. While it is tempting to assume that battery storage is the obvious complementary technology for intermittent renewables, we find that over-reliance on batteries for storage may add costs that could have been avoided, for example, by better integration of demand flexibility resources.

As we see in figure 5.7 below, a system that relies heavily on batteries as an energy storage option for most flexibility needs would be significantly more expensive than one that depends on demand side response or a balanced portfolio of flexibility options we explored in section 4.

Figure 5.7 Battery energy storage is one of the most expensive resources to meet daily balancing need in 2018



Source: CPI Energy Finance

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 Tamil Nadu 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.

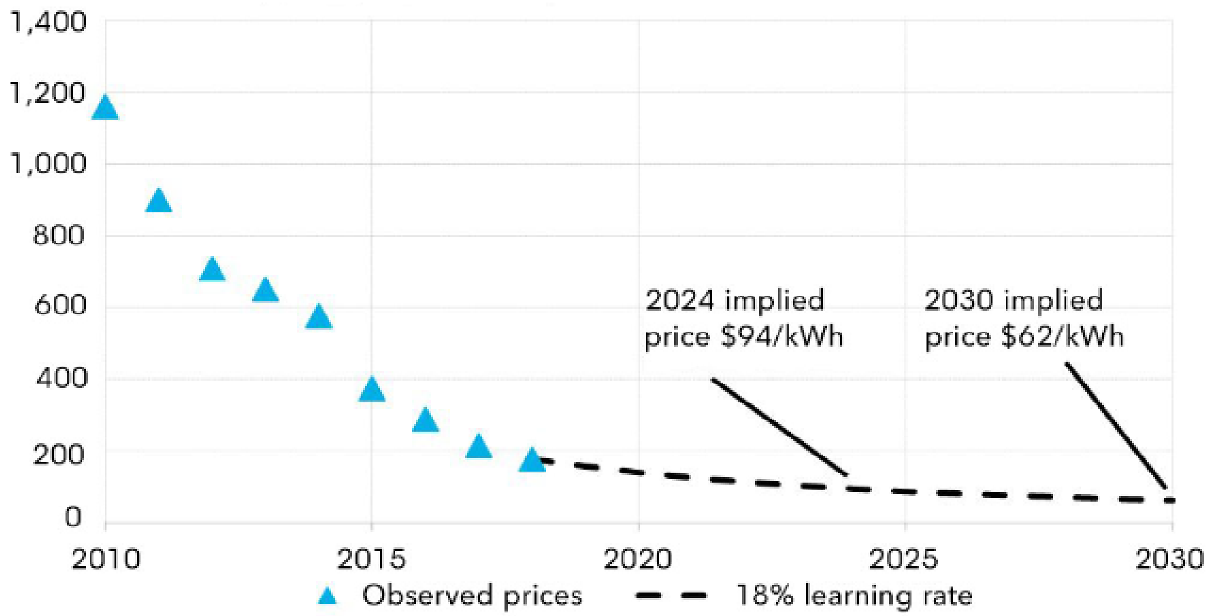
However, optimizing location of batteries, use of batteries in multiple services such as ramping, daily balancing, and reserves, and incentives to develop, install, and dispatch storage all require significant improvements in India electricity markets. These are the same improvements that are needed 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[16] 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 5.8).

Figure 5.8 Lithium-ion battery pack cost projects ($/kWh - Real 2018)

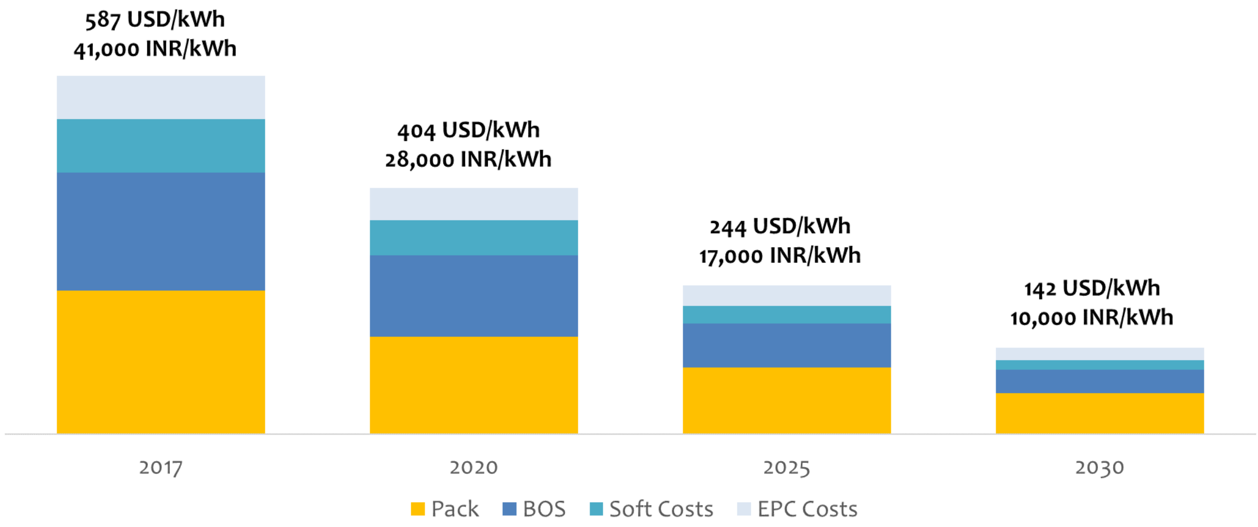


Source: BNEF

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 5.9)

16 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 5.9 Battery energy storage systems – installed cost projections for India ($/kWh)



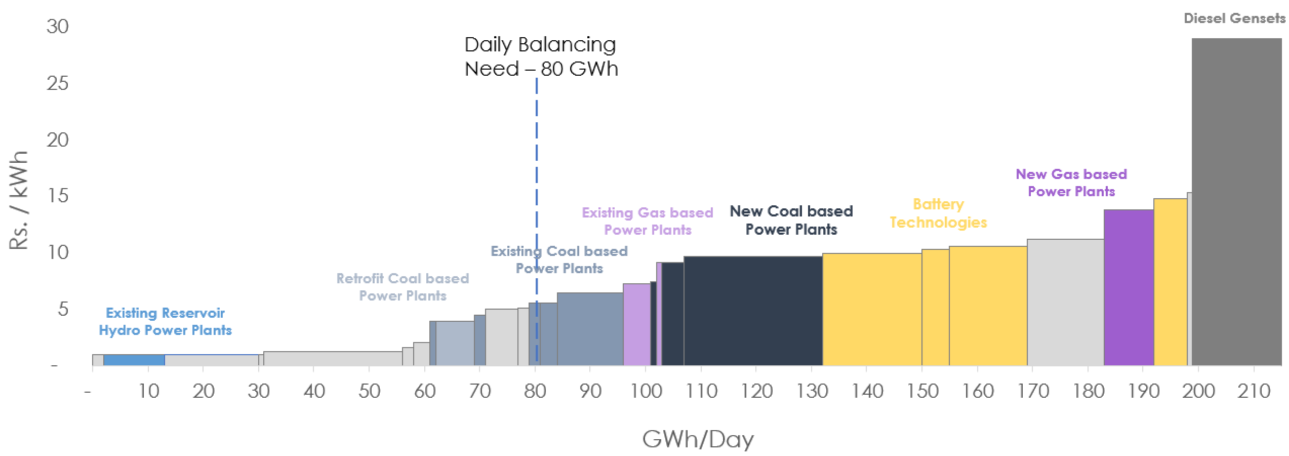
Source: Based on McKinsey figures, assuming India BOS discount of 25% by 2030, increasing from no discount in 2017. 2030 extended based on 2017-2025 CAGR. Exchange rate - 70 INR/USD.

5.2.2 STACKING OF SERVICES, COMBING VALUE STREAMS

Even with the projected reductions in costs, batteries are unlikely to become fully competitive with powerplants or demand response for many flexibility requirements, if batteries are built exclusively to meet specific flexibility needs. We see from Figure 5.10, battery storage starts becoming relatively more competitive to meet daily balancing needs in Tamil Nadu. However, it is still at a premium to the marginal resource, i.e., new supercritical pithead plants.

Figure 5.10 Battery energy storage will continue to be relatively expensive source of flexibility in 2030

Daily balancing supply curve 2030



Source: CPI Energy Finance

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.

5.2.3 STACKING, INTERNATIONAL EXPERIENCE

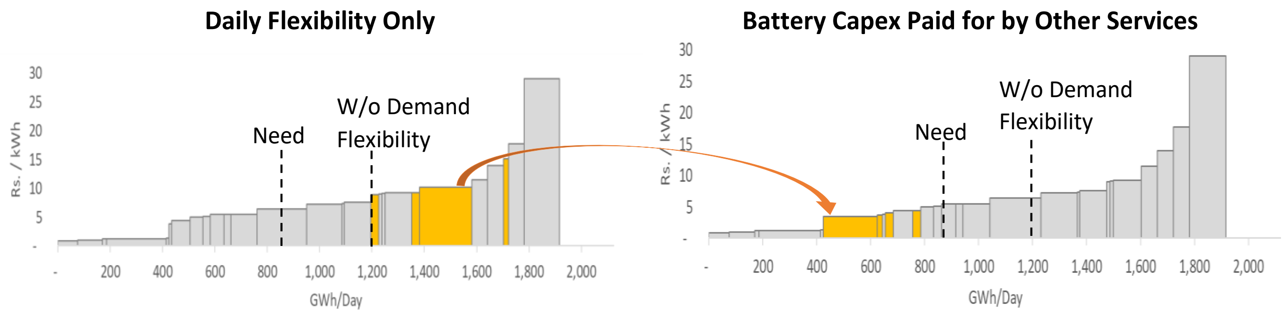
In Figure 5.11, a review of storage projects in the US reveals that most projects already combine value streams. There are many possible ways to combine applications. However, some applications are better suited for stacking such as combining energy shifting with bulk system support or voltage support, 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 5.11 Many storage projects already combine value streams

5.2.4 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 5.12). 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 5.12 The impact of multiple services on battery flexibility costs (2030 costs)



Source: CPI Energy Finance

5.2.5 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 5.13).

Different business models include:

- **Substation/ Wholesale**. TANTRANSCO, TANGEDCO or an IPS[17] 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 TANTRANSCO or TANGEDCO 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 5.13 Different storage models will be able to effectively meet different flexibility needs

	Short Term Reserves	Ramping	Daily Balancing	Peak Shifting	Seasonal Shifting	Trans. Deferral	Dist. Deferral
Substation/ Wholesale	✓✓	✓✓	✓✓	✓✓		✓✓	✓✓
Behind the Meter -Small Scale	✓✓		✓✓	✓✓			✓✓

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

Behind the Meter **-Large Scale**	✓✓	✓	✓✓	✓✓	✓	✓	✓
System Aggregator	✓✓	✓✓	✓✓	✓✓		✓	✓✓
ESCO	✓✓	✓✓	✓✓	✓✓		✓	✓✓
Co-located with RE	✓✓	✓✓	✓✓	✓✓		✓	✓✓

Source: CPI Energy Finance

5.2.6 BARRIERS TO FLEXIBILITY FROM ENERGY STORAGE

Battery energy storage faces a number of market and policy barriers, including:

- **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 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.
- **Policy hurdles**: CERC recently upgraded the LTOA and MTOA Connectivity Regulation, that would now allow battery energy storage to sell energy back to the grid and the market, a prerogative otherwise limited to generators[18]. The recently updated Real-time markets and Ancillary Services market regulations have started to pull together a market place 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.

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

5.2.7 MARKET REFORM: INTEGRATING ENERGY STORAGE

Although energy storage is expensive in the immediate term, market reforms have an essential role to play in creating the right conditions to maximise the value of these high-cost assets. Steps taken today have the potential to create a big impact in the future. While powerplant flexibility has limited potential to scale and demand flexibility has the potential to provide flexible capacity at the lowest possible cost, energy storage has scope to provide multiple types of flexibility which the other two sources cannot provide. 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 recommendations for Tamil Nadu.

Tamil Nadu could again, put itself at the forefront of developing this technology by assessing the scope for a domestic manufacturing base and for assessing the value of business models for battery charging, potentially run by TANGEDCO itself.

Battery energy storage is almost non-existent in Tamil Nadu but our analysis shows that battery energy storage could be play a significant role in meeting future flexibility needs in the state, especially from 2030 and beyond. The main areas that Tamil Nadu’s policymakers and TANGEDCO could address to overcome barriers:

- TNERC regulatory adjustment to recognise battery energy storage as a generator
- Locationally granular data to establish the choke points in the state’s distribution grid for deployment of storage capacity
- Tariff constructs for standalone storage, both at the grid level as well as behind the meter.
- Tariff constructs for solar + storage that would incentivise flexibility and reflect locational value
- Temporary market carve-outs for storage to participate in fast frequency response and broader ancillary services
- Establishing the availability of essential supply chains to support battery manufacturing in Tamil Nadu to support its EV and stationary storage ambitions

A series of pilots with mandated deployment of storage capacity, solicited from industry participants and service providers through tenders would be a good starting point to establish the specific flexibility value add from storage.

Besides these steps, Tamil Nadu will need to remove barriers to the deployment of energy storage in a way that maximises its value and adaptability to different flexibility services. Smart meters and controls will be required for any future grid system, as communications between assets, systems and markets is essential to full and economically efficient integration of all the technologies that will power the grid.

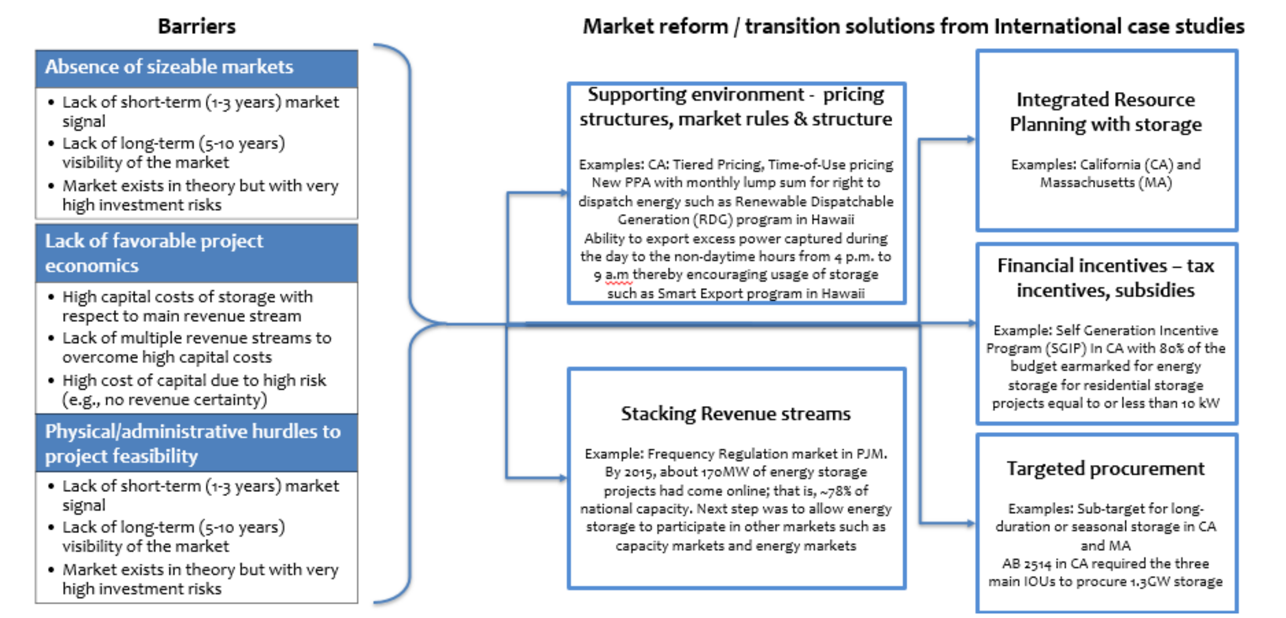
Lack of deployment of smart technologies that can communicate with the system, for example, would prohibit the use of energy storage as a demand flexibility option for domestic demand, as it is essential for the aggregation across large consumer bases. Meanwhile, the absence of SCADA system as distribution substations (110kV) and real time communications hinders real-time responsiveness, an essential feature of daily shifting in demand flexibility context. A regulated mandate for data capture could stimulate investment in the deployment of smart equipment.

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 Tamil Nadu's flexibility needs by enhancing flexibility from powerplants

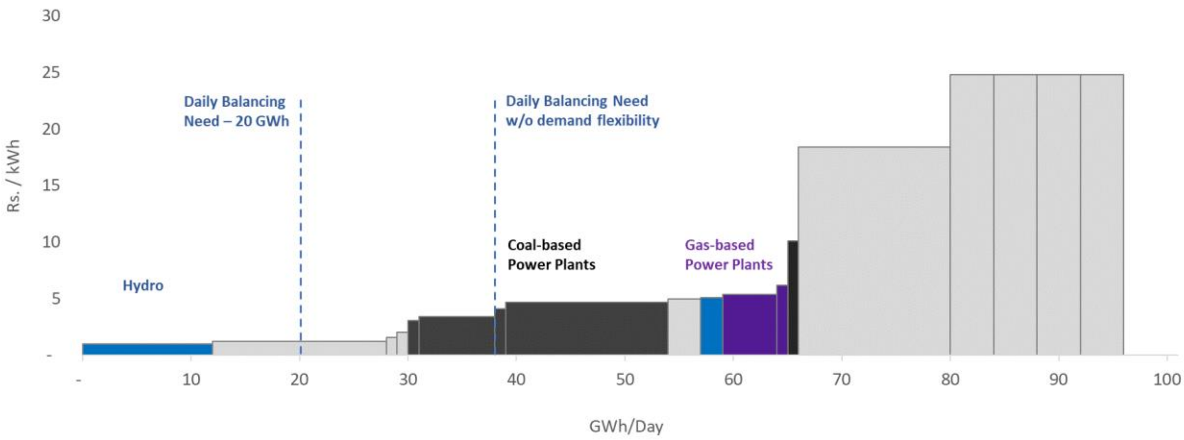
Tamil Nadu already uses its fleet of power assets flexibly, but this is largely limited to turning down coal plant during times of excess generation from wind during the monsoon season. As we showed in section 4, thermal powerplants have an important role to play in expanding Tamil Nadu's range of flexibility options in a portfolio that blends this resource with demand flexibility and energy storage.

Thermal powerplants underpin Tamil Nadu's baseload generation, with a combined capacity of 10.2GW, of which 4.3GW are state-owned coal assets and 546MW are state-owned gas assets, with the remainder contracted from independent power producers and central generating stations[19].

By reducing technical operating minimums for state-owned plant from 70% to 55%, we see a corresponding reduction in excess energy, system costs and CO2 emissions, under all scenarios bar one. But all metrics drop dramatically when thermal assets are blended with flexibility from storage and demand. Therefore, expanding flexibility from thermal assets only makes sense in the context of lower carbon resources. In addition, the scale of this thermal flexibility is naturally limited by India's decarbonisation goals.

Figure 5.14 Tamil Nadu's hydro and coal plants were cheapest sources of daily flexibility in 2018

Daily balancing supply curve 2018



Source: CPI Energy Finance

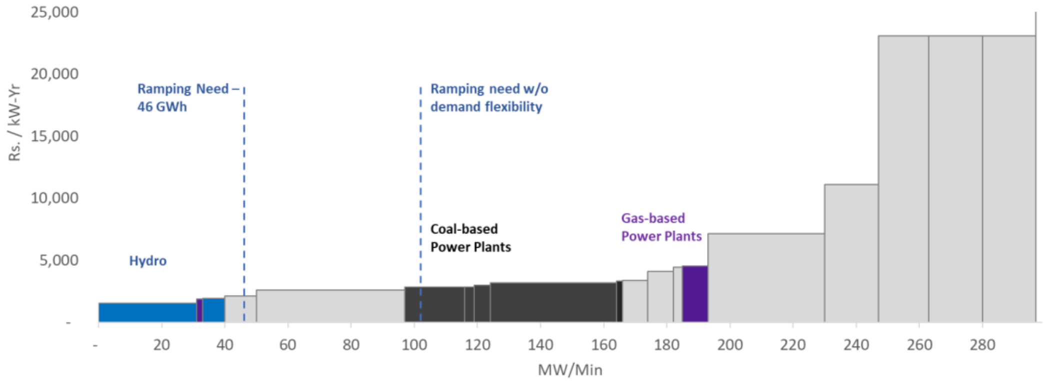
Out of an overall capacity of 19GW, thermal and hydro capacity represent 36% and 8% respectively of Tamil Nadu's total installed and contracted capacity as of 2019. These resources also offer the cheapest source of daily flexibility (see figure 5.14).

By 2030, the state's thermal capacity is expected to increase to 17GW with the addition of 7.5GW of new and more efficient coal assets (net 4.5GW after retirements), 1GW of lignite and 1.5GW of gas while hydro, excluding pumped hydro, will remain constant at 1.9GW[20]. By that time, we forecast that thermal assets will still be the cheapest flexibility resources for daily balancing and ramping.

After these adjustments, we found that thermal powerplants can provide 7GW of flexibility capacity for daily balancing to the system, of which about 600MW would require significant plant upgrades and investment. This 7GW could be used for daily balancing.

[19] TNEB Statistics - 2018
[20] Broad Status Report – 2018 – Central Electricity Authority

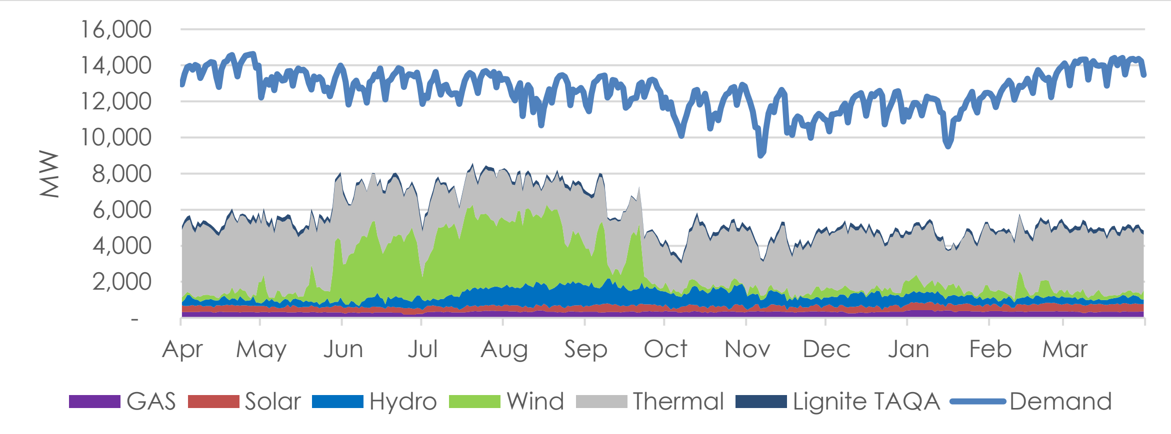
Figure 5.15 Tamil Nadu's coal plants and existing hydro will be the cheapest sources of ramping capacity in 2030



Source: CPI Energy Finance

Contributions from each power source is shown in figure 5.16 below. Additional demand is met through 750MW contracted from independent power producers and 6,000MW from centrally owned generators, and a much smaller amount from the power exchange.

Figure 5.16 2018-19 Demand and generation from wind, solar and state-owned powerplants



Source: CPI Energy Finance

5.3.1 COAL-FIRED POWERPLANTS AND FLEXIBILITY

By 2030, we estimate that powerplants can provide up to 7GW of flexible capacity, 600MW of which would require plant upgrades and changes in the cost recovery mechanisms. A further 1.98GW of retiring coal capacity would need to be retrofitted for maximum flexibility to enable plants to run at a technical minimum of 40%.

The flexibility potential of older coal powerplants is limited by design and operating practices as well as contractual constraints. For our analysis, we have given respite to the very old state plants, reducing their flexibility floor to 55%, while all other coal plants – state owned as well as contracted from the centre (i.e., owned by central government) and IPPs can run as low as 40%. Costs associated with these upgrades could be compensated through contractual arrangements and the removal of production penalties.

Under the Current Policy Scenario (table 5.4), there are only incremental benefits from additional coal flexibility. However, as we saw in section 3, these metrics all benefit from blended portfolios.

Table 5.4: Summary of changes to flexible operations – Current Policy Scenario

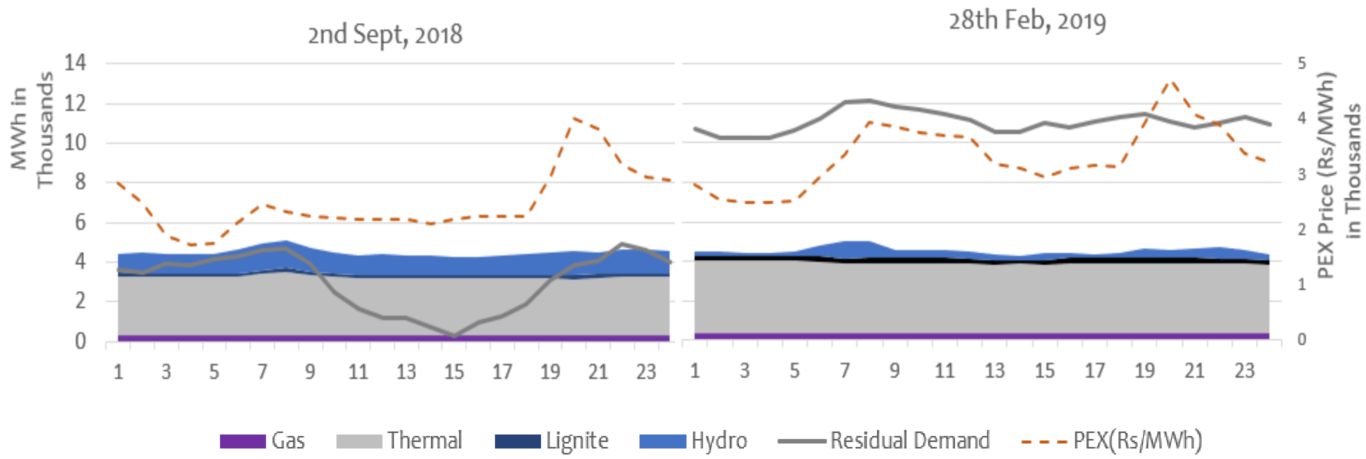
Scenario	Implied minimum PLFs	Excess energy	System cost (Rs/kWh)	CO2 emissions
Base case *Without additional flexibility*	SGS at 70%, CGS at 55%	13.6%	5.2	0.44
Medium powerplant flexibility – With Retrofits	All coal capacity at 55%	13.9%	4.9	0.45
High powerplant flexibility - with Retrofits	Old SGS at 55%, all CGS and new SGS at 40%	13.5%	4.8	0.44

Source: CPI Energy Finance

Today, around 32% of Tamil Nadu's installed and contracted capacity is coal-fired. Although the state's coal-fired assets have already adjusted to help the state address the seasonality of supply driven by the wind capacity in its current portfolio, its thermal fleet plays a limited role in managing daily variability.

Figure 5.17 captures the demand and generation profile from a typical day during a high renewable generation period (2 September) and from the low renewable generation period (28 February) in 2018-19. These graphs show that the state generation companies and IPPs, while materially different across the two days, do not show much diurnal variation. Hydro capacity plays a greater role in managing the variability within the 24-hour period by providing ramping capacity at the morning peak.

Figure 5.17 Daily generation from coal and lignite vs residual demand during a typical day in high and low wind seasons



Source: CPI Energy Finance

These charts also show the generation profile from all state-owned resources, all powerplants except wind and solar. These resources are utilised by the state to meet the residual demand (solid grey line). In the left-hand side chart above, we can clearly see that during the high wind season, on a typical day in September, the state has enough resources to meet its residual demand on its own. In the right-hand side chart however, during the low wind season, a typical day in February, state resources are no longer sufficient to meet residual demand and additional capacity from independent power producers and central generating stations are key to meet the need for an additional 4.3GWh (vs. the day in September).

Residual demand drops to zero for a significant amount of time on the typical day shown in September when solar generation peaks, indicating a substantial amount of thermal generation that is not required.

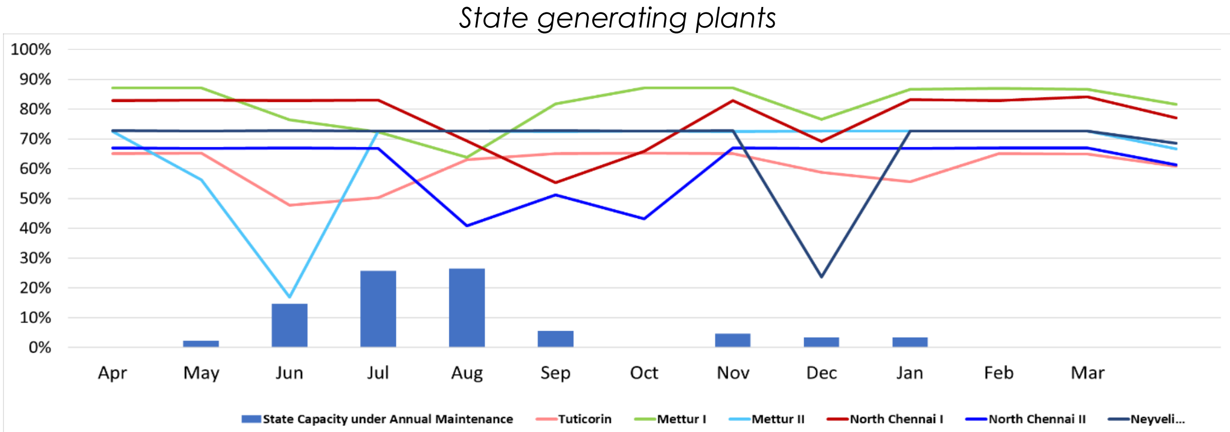
Surplus energy that is wasted has the potential to raise overall costs to the system as the energy produced is still contracted and therefore must be paid for. If no additional flexible capacity is available, the ability to recover the cost of surplus generation will be subject to demand and price at the exchange.

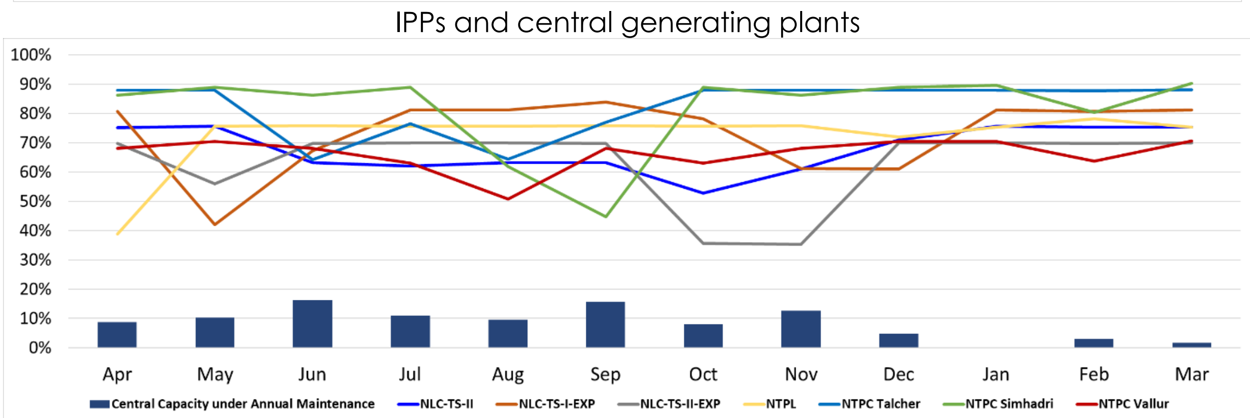
While the discussion about the curtailment of renewables, i.e. shutting off renewables when there is more energy than required on the system, is not a debate unique to Tamil Nadu, it may make sense to examine ways of curtailing the state's thermal assets to balance the output more efficiently – and economically. Lost revenues for thermal assets could potentially be counteracted by increasing the range of flexibility services provided by thermal assets.

In addition to these costs, on a typical February day like the one shown above, TANGEDCO is exposed to the peak in spot prices on the power exchange to cover shortfalls, in particular for the morning peak. While contracts set prices at between Rs 2000/MWh and Rs 5000/MWh depending on the merit order, additional procurement from the power exchange can be costly and is not always a reliable means of meeting the shortfall.

On this basis, investments and incentives to enable the state's thermal fleet to operate more flexibly could potentially save TANGEDCO money and provide additional revenues. Once again, as we show in section 3, when combined in a blended portfolio of flexibility resources, the benefits of flexibility from thermal assets are amplified.

Figure 5.18 State and central generating station profile (plant load factor) and capacity under maintenance for Tamil Nadu, 2018-19





Source: LGBR, 2018, CPI Energy Finance

Figure 5.18 above shows the seasonal generation profile for the state-owned generating stations as well as the contracted capacity from IPPs and central generating stations. Both sets of plants show a drop in utilisation during the high wind season (June-August) because annual maintenance schedules are planned to coincide with the monsoon season. But further flexibility is extracted by turning down the overall utilisation of these plants.

State gencos show a greater participation in seasonal flexibility with an average utilisation of 55% for the monsoon months (Jun/Jul/Aug/Sep). Contracted capacity from central generating stations show a less consistent pattern, with plants like Simhadri, NCTPS Stage II and Talcher showing seasonality, e.g. a10% drop in PLF during monsoon. The rest of the central generating portfolio shows a more muted impact, at least in part because their capacity is contracted across multiple states with different flexibility requirements and maintenance schedules. In addition, central stations are mandated to withhold a part of their capacity for providing spinning reserves, which restricts scheduling maintenance to coincide with peak wind capacity.

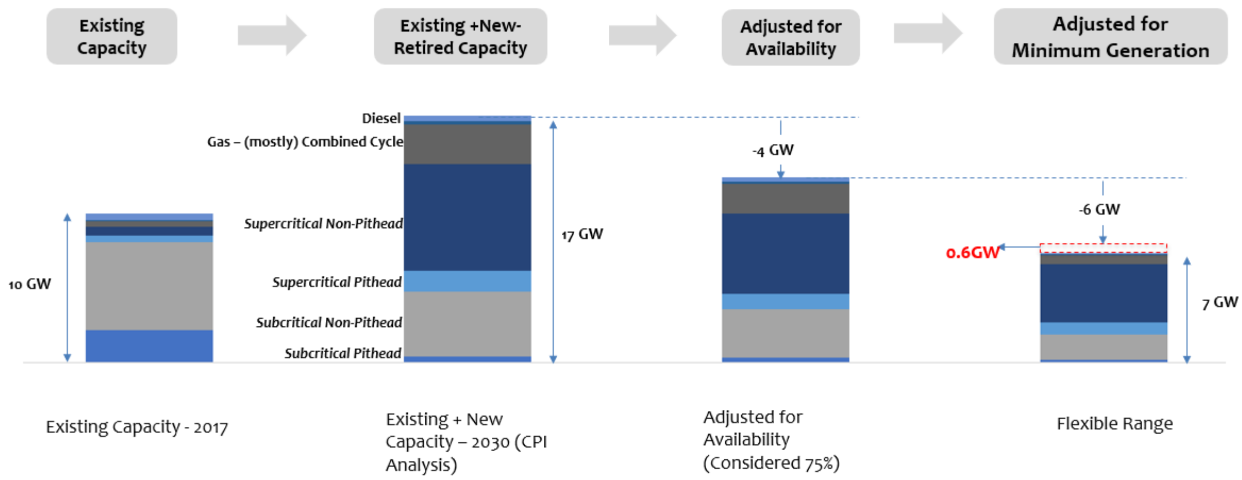
While we see that state-owned generation schedules are responsive to the monsoon season, that is not the case for all of them – Neyveli and Tuticorin being the obvious examples. In addition to the state-assets being scheduled to coordinate with seasonal balancing needs, there may yet be more scope to increase flexible reserves from scheduling IPPs – but this might be limited by their commitment to supply power to other states.

5.3.2 ADDITIONAL FLEXIBILITY FROM COAL-FIRED POWERPLANTS

Assumptions about flexibility resources such as ramping from thermal assets are based on the degree to which plants can ramp up or down. Lowering the mandated technical minimum allows for more electricity to be dispatched to provide flexibility beyond seasonal balancing, such as ramping to balance predictable changes in supply, eg when PV solar supply drops as demand increases, or for reserves to keep the lights on if demand spikes or another plant fails.

Based on our discussions about the expansion of flexibility of coal-fired power plants with TANGEDCO, NTPC (Operations) and Siemens, we understand that while there are misgivings about their potential to provide flexibility, most plant are able to run at lower utilisation levels (plant load factors) than the mandated technical minimums. We understand that NTPC plants are technically able to run with plant load factors (PLFs) as low as 40%. At least three state-owned coal-fired plants run at 50-55% PLF during the high wind season. The c.9GW of new coal capacity planned in the next decade is expected to be able to operate more flexibly, but the TANGEDCO team advised that there are five older plants that are limited by the boiler design in delivering greater flexibility by a reduction of PLF to c.55%.

Figure 5.19 Flexibility potential from thermal power plants 2030



Source: CPI Energy Finance

In figure 5.19, we identified that coal plants, especially state gencos, provide seasonal balancing but play a limited role in daily flexibility. During the high wind season, this creates surplus generation on the system, even after utilising hydro flexibility capacity, and that in turn results in higher system costs. On a day like 2 Sep 2018, when the exchange prices are also low, recovery of cost for this excess energy on the grid is unlikely to materialise. A more energy- and cost-efficient approach would be to combine lower technical minimum with two shifting of part of the coal portfolio, where plants are already scheduled to shut down and start again, to reduce the overgeneration of c.35GWh of electricity within a 24-hour period.

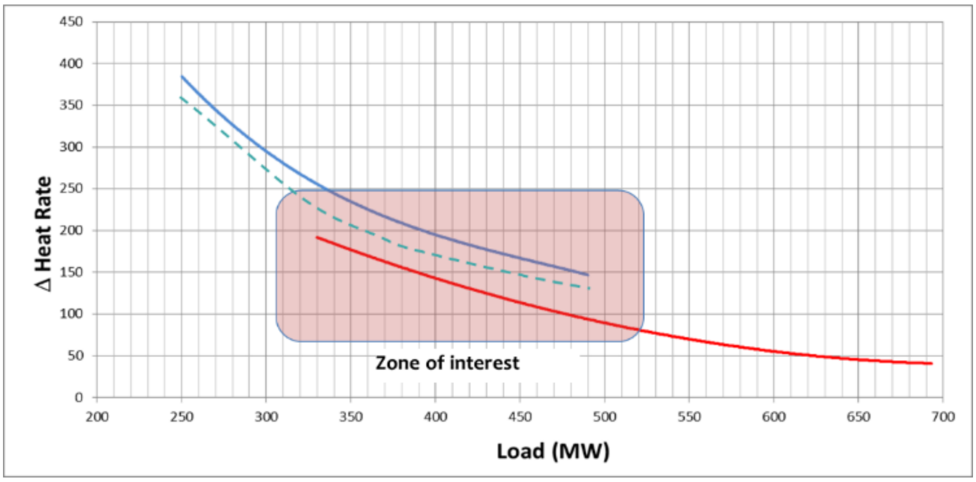
We estimated how much flexibility could be available by 2030 by identifying which plants could provide flexibility. We adjusted these numbers for additions, retirements, availability (that is, maintenance and repair down time) and then minimum generation. After these adjustments, we found that thermal powerplants can provide 7GW of flexibility capacity for daily balancing to the system, of which about 600MW would require significant plant upgrades and investment. This 7GW could be used for daily balancing.

5.3.3 COSTS OF PROVIDING ADDITIONAL FLEXIBILITY FROM COAL PLANTS

There are at least five ways that offering flexibility could increase the costs to the powerplant operator and to the system – all of which could be subject to adjustments, incentives, innovation or regulation in reforming the market:

1. **Efficiency penalty**. Thermal powerplants are less efficient when they operate below their maximum rated capacity. Figure 5.20, provided by Siemens, shows how the heat rate of a 500MW coal-fired powerplant would decline at lower load factors. This plant could operate at a minimum load of 50% or 250MW. We factor in 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 degradation of Station Heat Rate (SHR) and auxiliary consumption.

   Figure 5.20 Impact of part-load operations on efficiency

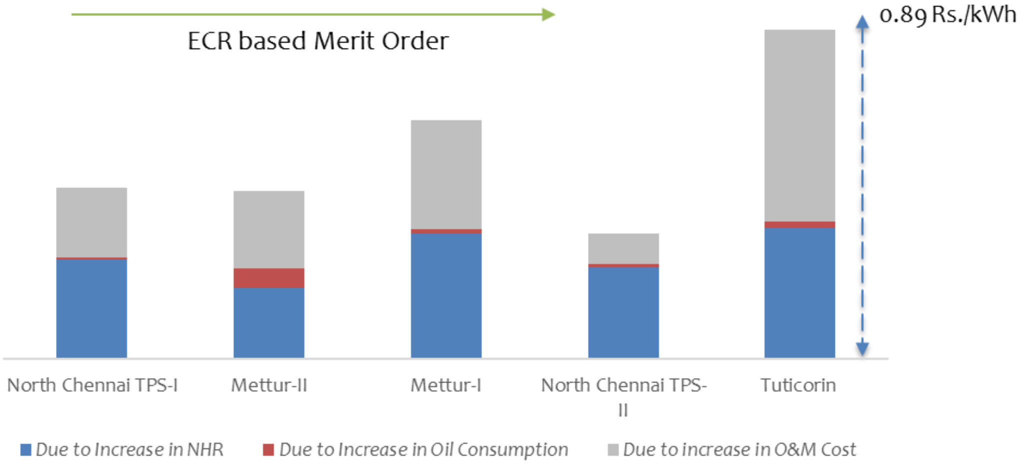
   Source: Siemens

2. **Start-up costs.** While fuel is saved by shutting down a plant, restarting and bringing it back online incurs extra costs including fuel, operating costs, etc. The Grid Code Regulation provides compensation for additional secondary fuel oil consumption due to frequent start and stop. 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.

3. **Operating costs**. Operating plants more flexibly requires changes in temperature and starting and stopping equipment, all of which puts strain on the equipment, requires increased maintenance and monitoring. Additionally, plant failures and more frequent repairs may be more likely. Quantifying the impact of start-stop operations have on costs, maintenance and failures, and how investments and changed operating procedures can reduce these costs, will require more detailed assessments. Regulations do not provide any compensation for additional O&M expenditure due to frequent starts and stops. However, we have factored into our analysis some O&M cost increases for flexibility, based on the results of the GTG-RISE Program by M/s Intertek, at Ramagundam TPS and Jhajjar TPS of NTPC[21]. CPI analysis shows that the five state-owned plants could have incurred additional costs of up to INR 0.89/kWh based on the seasonality drawn from their monthly utilisation profiles (figure 5.21).

Figure 5.21 Additional cost due to seasonal flexibility – State Generation plants



Source: CPI Energy Finance

4. **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.
5. **Upgrade costs**. 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 1 billion INR for a 210MW unit, but 1.5 billion INR for a much larger 500MW unit. However, Mettur TPS-I and Tuticorin TPS with a cumulative capacity of 2.8GW retiring in the next couple of years and these could be potential candidates for retrofits and modernisation to add flexible capacity over the next 10 years.

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

5.3.4 FLEXIBILITY POTENTIAL FROM GAS FIRED POWERPLANTS

Gas based power plants have the technical attributes that allow them to operate more flexibly than coal-based units. In Tamil Nadu, the gas fleet is generally used as baseload and can also meet peak load requirement as the start-up and ramp rates for gas-based generation is higher as compared to coal-based plants. The fleet's flexibility is seriously challenged by the lack of on-site storage facilities and the gas supply must be used as it is delivered. However, with adequate storage facilities, natural gas could play a significant role in providing system-critical flexibility services if prices and incentives are set right.

Combined cycle gas turbines (CGT) can be operated more flexibly, and can contribute to both ramping and daily shifting through modularisation, as having the same capacity through multiple units reduces both start up and ramp times and increases ability of the capacity to adapt efficiently to frequent starts and stops.

Tail Nadu currently has close to 1GW of gas-fired generation capacity, of which 516MW is state-owned and the remaining is contracted through private producers[22].

Table 5.5: State owned gas-fired capacity in Tamil Nadu in 2018

Plant	Fuel	Source	Commissioned	Capacity (MW)	Mode of Operation	Average Cost of Generation (Rs./KWh)	PLF	Gas Price (Rs./SCM)
Basin Bridge GTPS (Naphtha)	Naphtha		1996	120	Open cycle	10.76	0.6%	35.00
Thirumakottai GTPS	Natural gas	ONGC Wells	2001	107.88	Combined cycle	2.45	80%	12.34
Valuthur GTPS	Natural gas	ONGC Wells	P1- 2003 & P2-2008	187.20	Combined cycle	2.34	80%	11.89
Kuttalam GTPS	Natural gas	GAIL India	2003	101	Combined cycle	2.48	80%	12.61

Source: TNEB, Tariff Order 2017-18

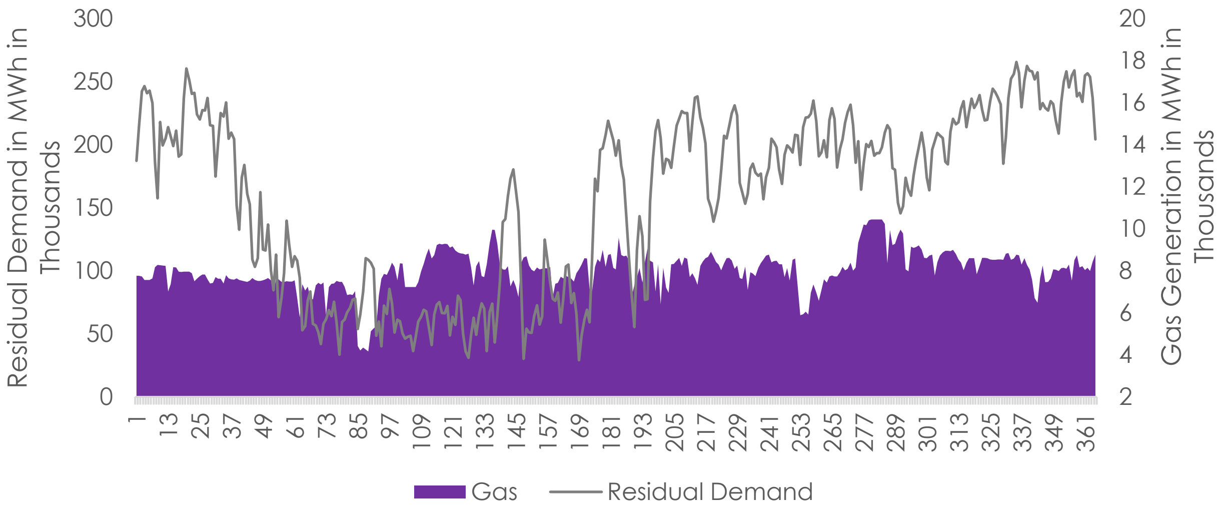
Tamil Nadu's gas generation, especially the majority of current installed capacity, benefits from access to cheap natural gas from the KG Delta basin. The average domestic gas supplied to gas-based power plants during 2017-18 was only 25.71 MMSCMD, which is 70% short of the allocation and forces plant to dramatically reduce generation. However, low-cost fuel is depleting and increasing dependency on the high cost imported liquified natural gas (LNG) or even higher cost fuels, as is the case with Basin Bridge GTPS which shifted its fuel from natural gas to naphtha because of the low availability of natural gas.

Currently available gas generation capacity in Tamil Nadu operates as a baseload as can be seen in figure 5.22 below. This is largely driven by the take or pay nature of the fuel supply contract backing this generation capacity. Each of the gas plants are expected to pay for the agreed offtake volume of natural gas irrespective of whether the volume of gas is utilised. With

[22] TNEB Statistics 2018

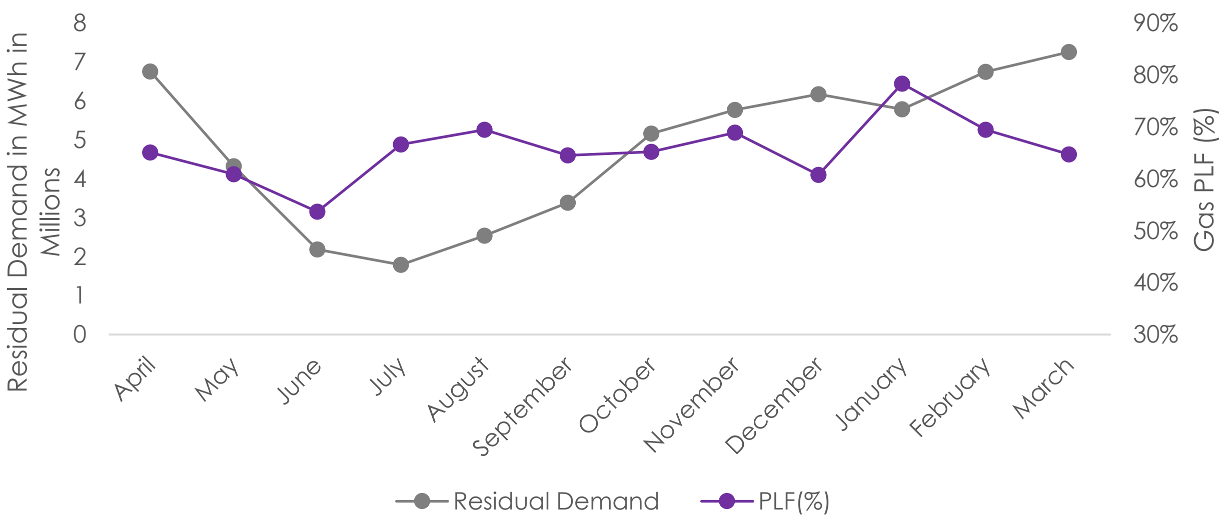
the lack of any storage facilities within the system, powerplants are forced to maximise the utilisation of this cheap contracted gas (natural gas cost of Rs 350/ mmbtu vs landed LNG price of Rs. 655/ mmbtu) and run the plants as a baseload capacity irrespective of the residual demand (figure 5.23).

Figure 5.22 Residual demand vs gas generation (MWh - 2018-19)



Source: TNEB, CPI Energy Finance

Figure 5.23 Residual demand and gas-fired plant load factor - 2018-19



Source: CPI Energy Finance

5.3.5 COST OF FLEXIBILITY FROM GAS FIRED POWERPLANTS

Technical flexibility from CCGT power plants is limited by the steam turbine and the heat recovery steam generator (HSRG) (IEA, 2018). Any change in its design and operational characteristics significantly impacts its overall flexibility. HSRG are typically thick-walled and require a longer time to warm up and hence replacing it with thin-walled component may enable start-up in a shorter time. A similar change in component thickness in the steam turbine reduces the start-up time.

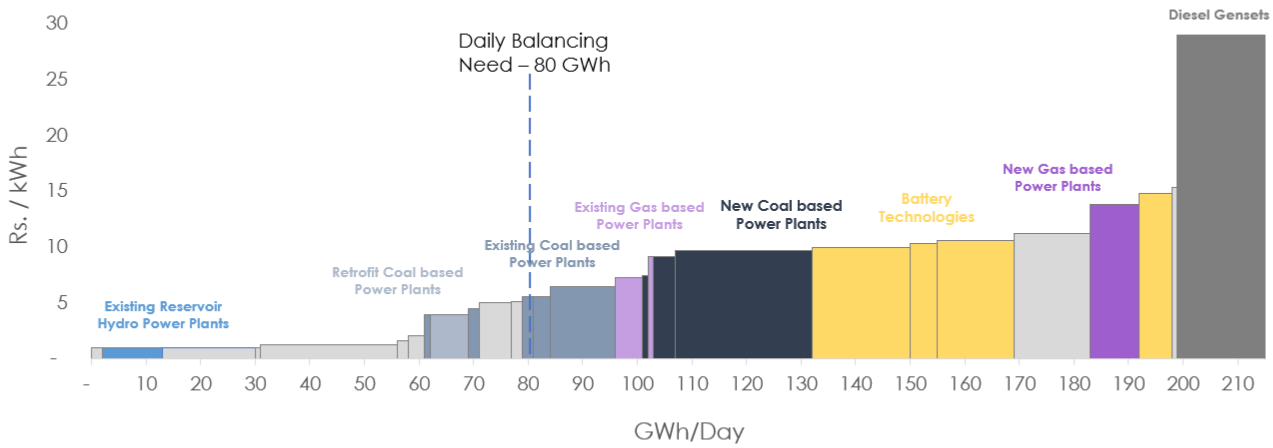
One way to achieve flexible operation is to add a bypass unit in CCGT plants so that the waste heat from gas turbine is not captured and the steam bypasses from HSRG to condenser, enabling it to operate like an OCGT plant. However, such replacement is very capital intensive and the cost might be equivalent to building a new flexible unit. The trade-off between the gains and cost involved to increase the flexibility of the plants needs to be well assessed.

Another approach would be modularisation across a number of units in the gas fleet, allowing for faster ramp up for individual units and less heat loss from flexible operation. The minimum loading for gas-fired power plants is lower than the coal-fired units and they can also provide better ramping without any additional capital investment.

In Tamil Nadu, the total installed gas generation capacity is c.1GW, but this capacity made up of units of c.100MW. Smaller units allow for a more modular approach and hence scope for efficient participation in flexibility services. The average PLF for gas generation is above 50%, but these plants could be run more flexibly with PLFs as low as 30% based on their designs. Subject to the availability of cheap natural gas, our analysis shows that a potential 866MW could be available for flexibility from the installed gas capacity.

Our analysis shows that gas-based power plants, especially currently installed gas plants with access to cheap natural gas, when fully flexed can contribute around 15GWh/Day at an average cost of c.Rs.8/kWh to the daily shifting requirement. This is more expensive than the marginal resource of existing non-pithead subcritical coal and assumes that all demand side potential will materialise in the medium case. Nevertheless, gas could play a vital role in providing some flexibility services that require fast ramping for example, a service which should be able to fetch a premium given the right market conditions.

Figure 5.24 Daily balancing supply curve – cost comparison of gas-based plants with other resources - 2030



Source: CPI Energy Finance

5.3.6 HYDRO FLEXIBILITY

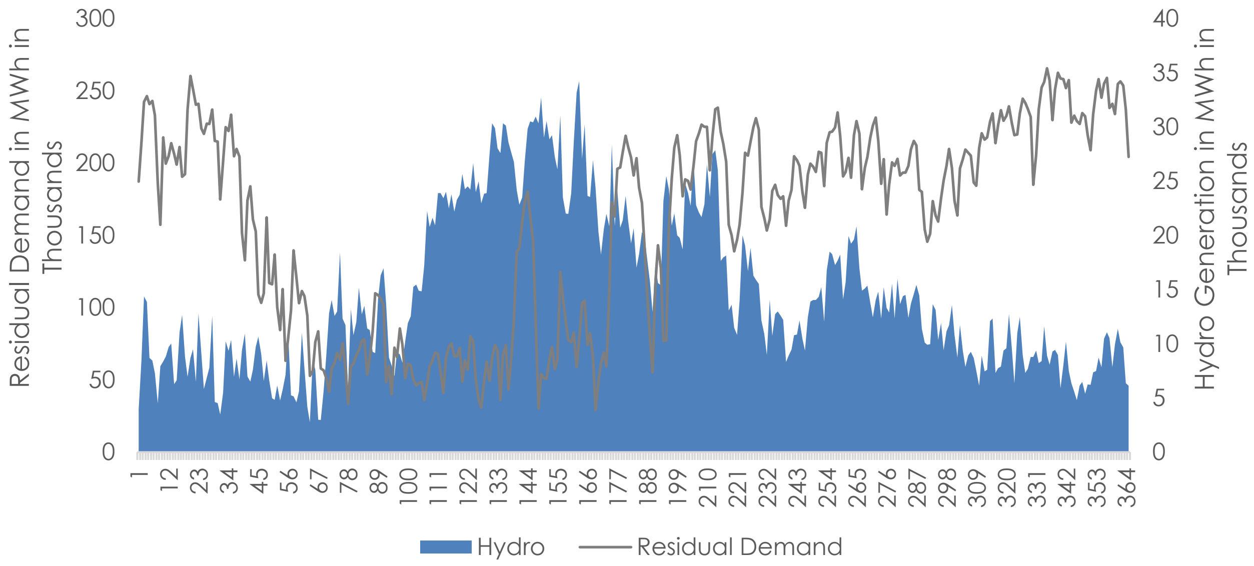
Hydroelectric generation typically is utilized in the electricity system for balancing purposes and to provide backup. Hydro is therefore considered a valuable generation asset, especially in accommodating large shares of renewable capacity. The installed hydro capacity in Tamil Nadu is close to 2,307MW, out of which 1,430MW is non-irrigation based, while 877MW is irrigation based[23].

Out of the non-irrigation reservoir capacity of 1,430MW, pumped hydro capacity of 400MW and another 400MW of reservoir-based capacity, totalling 800MW is available for flexibility services which TANGEDCO utilises fully. The limited flexible capacity from reservoir-based hydro can be primarily attributed to the concentrated inflows received from July to October that forces

[23] TNEB Statistics 2018

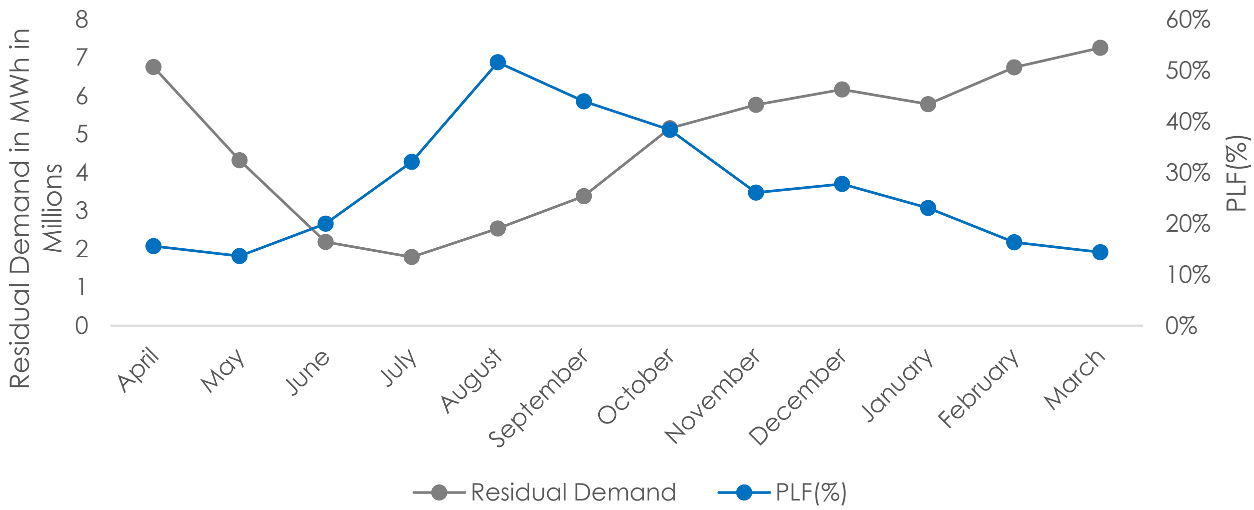
almost 630MW of the capacity to operate at full load during this restricted period with no potential for flexibility services figure 5.25 and 5.26).

Figure 5.25 Residual Demand and Hydro Generation – 2018-19



Source: TNEB, CPI Energy Finance

Figure 5.26 Residual Demand and Hydro PLF (%) – 2018-19



Source: CPI Energy Finance

5.3.7 BARRIERS TO FLEXIBILITY FROM POWERPLANTS

Power purchase agreements and contracts for powerplants, especially coal have typically been 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, Tamil Nadu'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:

- ***Scheduling and dispatch:*** The existing contracts allow the utility to schedule the power from its contracted capacity up to four-time blocks before the actual delivery. The option to recall prevents the generators from selling the unscheduled surplus to the grid.

If the utility allows the generator to sell the power in the day-ahead market, the contract mandates the generator to return two-thirds of the profits from the sale of surplus power with the utility.

- ***Auxiliary consumption***: Current contracts specify that the energy drawn from the state utility network for auxiliary consumption, such as river water pumping, ash water recovery, ash slurry booster pumps, etc, is netted off from the energy supplied by the generator to the utility. During flexible operations, the auxiliary consumption increases which ultimately increases the cost of generation because it raises the amount of power that needs to be generated to cover a plant's running needs and contractual commitments.
- ***Fixed cost recovery:*** The fixed cost recovery will be paid to the generating station if it achieves the target annual availability of 80%. If any power plant does not achieve its target availability, a fixed charge will apply on pro-rata basis as approved by the Regulator. Fixed cost recovery provided in the contracts is based on normative operating conditions of the power plants and doesn't consider additional expenditure due to part loading. Contracts and regulations in Tamil Nadu do not provide for any additional compensation to the power plants for their flexible operations.
- ***Additional capex:*** The existing contracts provide that any additional capital expenditure for renovation, refurbishing and modernization shall be passed through to the state utility subject to the regulator's approval. There is no clarity on pass through of any refurbishing costs if spent to increase the flexible operation of the thermal plants.

5.3.8 ADDITIONAL BARRIERS TO FLEXIBILITY FROM GAS-FIRED POWERPLANTS

- **Access to low-cost natural gas** – Declining natural gas supply over the last decade is a common problem for India's gas fleet. Tamil Nadu's gas plants are still supplied by one of the largest gas basins in India, the Krishna Godavari (KG) Delta basin. However even these deposits have seen a set back where the production from KG D6 have turned out to be far lower than the estimated 80mmscmd and are producing only 5.5mmscmd as of last year.

  GMR's 196MW Basin Bridge plant suffered a set-back due to the lack of fuel supply and after trying to replace natural gas with Low Sulphur Heavy Stock (LSHS) and then naptha, closed the plant in the absence of demand for its high-priced energy. The plant was decommissioned in 2018.

  It is more than likely that Tamil Nadu's gas fired generation will become increasingly dependent on high priced imported liquified natural gas (LNG) which would limit the potential of flexibility from gas plants from peaking needs and seasonal needs during low RE generation months.

- **Access to gas storage** – Before gas volumes start declining, there is still the potential to utilise gas generation capacity flexibly. However, the state genco will need access to cost efficient storage capacity. If no additional volume of natural gas was available, the existing gas capacity operating at 50% capacity could still shift c.20% of its generation, c. 250GW with access to storage.

5.3.9 MARKET REFORM & INTEGRATION FOR POWERPLANT FLEXIBILITY

Tamil Nadu 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 a few modifications to regulations, operations and contractual frameworks, our analysis has found that further flexible capacity could be provided, especially to meet Tamil Nadu's growing need for daily shifting and ramping. Thermal power plants are already providing seasonal flexibility by coordinating maintenance schedules with periods of peak wind production. 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, while Tamil Nadu's gas fleet also has constraints on infrastructure and will be increasingly expensive.

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.

The key role for markets in procuring the potential flexibility from gas would be to identify the availability of storage and how expenses incurred for those services could be recovered through the compensation for flexibility services rendered by gas generation

It is also clear that there are widespread needs for further technologies that would enable greater flexibility, such as monitoring and metering systems. Any future grid needs to include a 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. Tamil Nadu 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.

Tamil Nadu's policymakers and TANGEDCO could provide the regulatory framework and stimulus required to create such a market by taking the following approach:

1. State Grid Code Regulations for Tamil Nadu 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 Tamil Nadu make an investment case for procuring dedicated capacities for flexibility, especially seasonal 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, we understand that PPA terms are yet to be agreed, which gives the opportunity to set the parameters of the contracts around flexibility, allowing recovery of costs for higher SHR and auxiliary consumption, higher fuel consumption and 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 flexibility capacity, create additional revenue streams and provide cost recovery for both contracted plants as well as merchant capacity.

6. Conclusions

Increasing flexibility from thermal and hydro powerplants, developing demand flexibility and storage, planning the integration of transmission to enable and enhance flexibility and at a later stage, trading of flexibility, all require different types of policies and markets to those that will help integrate these options once they are developed. Achieving both effectively will require a focused approach towards:

- **Policy interventions and frameworks** that provide the necessary tools and routes for the creation and pricing of flexibility

  Amendment of state grid code for powerplants to change the focus of their operations from maximization of generation as erstwhile baseload resources to a flexible system where dispatch of powerplants can be switched between baseload or flexible capacity and the cost recovery as such is allowed through tariff mechanisms.

  Expansion of the category of energy suppliers, from traditional utilities would simplify and allow as is participation of demand and small-scale storage.

  In the medium to long term, Tamil Nadu would benefit from working with the national regulators for the evolution of the ancillary services mechanism into a market-based mechanism, would create the platform for participation of all sizes of 'flexible capacity' and scope for price discovery reducing over dependence on any one flexibility resource.

  Introduction of mechanisms such as financial transmission rights (FTR) and locational marginal pricing (LMP) to adequately price utilization of resources and identify grid congestion points, where additional grid capacity maybe required. As more renewable capacity is deployed, transmission waivers for renewables can be slowly tapered down.

- **Incentives and business models** that align service providers with overall needs and enable investors, consumers and others to monetise their supply of flexibility

  Amendment of contracts, to remove normative technical minimums and allow cost recovery that fully incorporates their operational and dispatch characteristics.

  Additional tools such as capacity mechanisms will also need to be considered at the national and state level for development of seasonal flexible capacity.

  Participation of industries and large commercials in flexibility services will require a clear assessment of the hard cost of flexibility for the participants across their captive generation, behind the meter backups as well as flexing their consumption. Additional incentives will be imperative to overcome the inconvenience threshold.

  Targeting flexibility from more retail demand e.g. households will require development of additional market participants such as aggregators and the development of additional service models for engagement of prosumers.

  Development of income algorithm for grid battery storage developer to attract private investors and multilateral financiers, and send signal to the market

- **Awareness** from consumers, potential storage investors and powerplant operators as to the potential and value of flexibility from their assets.

  Each flexibility resource would need to be addressed differently for this:

  - Capacity building among powerplant operators to address operational and behavioral barriers to powerplant flexibility and direct studies around each plant to correctly assess the cost/ payoff tradeoff

  - For demand side resources, especially industrial and large commercials, capacity building, direct engagement with industry leaders would be key to establishing the fact base for targeted procurement of flexible capacity
  - Storage resources, would require pilots, to both test the integration of the flexibility potential with the electricity system as well as send signals to investors and developers re state appetite

- **Technology** to make these flexibility resources and their deployment accessible, as well as reduce cost of flexible technologies.

  Vertical integration, for example bringing storage manufacturing to India, to reduce costs of storage and to create different types of storage systems that meet the various demands of the electricity market (industrial, renewable energy plus storage, transport, household and commercial energy back up/back-up generator replacement, etc)

- **Infrastructure** such as transmission to deliver flexibility, or the IT and metering systems to schedule and integrate flexibility

  Deployment of metering and monitoring systems (e.g. smart meters) to allow monitoring and measurement of the flexibility capacity input and matching flexibility demand and supply at the right price points.

  Setting up an agriculture pumping feeder separation programme for the state to tap into the flexibility of agriculture pumping demand.

  Deployment of additional transmission capacity intra state and with other states and interconnectors to facilitate seamless trading of generation as well as flexibility.

  Setting up an agriculture pumping feeder separation programme for Tamil Nadu

- **Data Mission** - there is a need for the development of a data mission for Tamil Nadu. Balancing supply and demand continuously is a data intensive exercise. A first step to creating this balance is to build a comprehensive set of data on both the value/ cost of flexibility over time and location, and the potential and cost of each flexibility option.
  - On the need for flexibility, data from the dispatch centres and trading markets form the core of required data, but more complete and comparable data will be needed. For example, nodal data for grid load would be important to understand both the scope of LMP as well as making decisions where new grid capacity is needed
  - On the supply of flexibility, a central catalogue of the capabilities of all India powerplants – and their potential upgrade – would be an important step, while estimates of daily demand, consumption patterns by end use (for example, agricultural pumping or residential air conditioning), and alternative consumption models are essential before we can develop programmes and incentives to shift these patterns.

7. Recommendations

Tamil Nadu 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.

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

1. **Enhance flexibility from coal-fired powerplants**
   - Powerplants are already a source of flexibility for Tamil Nadu, though on a limited scale. Utilisation of both hydro and coal capacity for flexibility is something that operationally ties in with existing strategies from TANGEDCO to manage Tamil Nadu's electricity system
   - Targeting enhanced powerplant flexibility for Tamil Nadu will deliver an additional 15% of the state coal portfolio as plants lower their utilization 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
   - Additional flexibility can be targeted by two shifting of coal plants in some seasons. Further, older plants could be utilized for meeting seasonal needs.
   - ➔ The enhanced power plant flexible capacity will not just be important for the increasing seasonal balancing capacity at TANGEDCO but also to deliver greater capacity for intraday balancing and ramping – flexibility which will be imperative to integrate greater solar in the system without increasing curtailment, reducing system costs and reducing emissions
   - ➔ 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. **Access agriculture flexibility**
   - Agriculture pumping, a fifth of Tamil Nadu's demand is a discrete block of energy consumption offering a highly adoptive flexibility source, as supply for irrigation pumping does not necessarily need to be provided at any particular time of day, creating the potential for this load to be moved across the day.
   - ➔ The separation of agriculture feeders has already been implemented successfully in certain states in India. Even if done in stages, the implementation of the separation of feeders has the advantage of delivering direct flexible capacity which can be available to the LDC for scheduling and managing the grid
   - ➔ Agriculture pumping, on separate feeders can provide a cost-effect option of not just meeting peak and daily shifting needs but also of ramping, where agricultural load could be ramped down at the same time that RE generation starts to taper, to reduce the additional ramping load burden on the system.
3. **Procure grid level storage**
   - 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 TANGEDCO team, 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.
- ➔ In the absence of any precedents, direct procurement by the state would be key for initial projects and creating signals for larger scale investments.

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

There are some medium to long term tools and technologies with potential to make a significant impact on the flexibility availability for Tamil Nadu but these options will need targeted approach today in the form of pilots, mandated procurement and holistic market design

1. **Run pilots for industry demand flexibility and engage with captive generators**
   - One significant source of flexibility is expected to be industry demand, especially industries with conventional captive generation capacities. This offers a potential for daily as well as seasonal 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 understand the incentive structures that would make such arrangements attractive.
2. **Procure behind the meter (BTM), large scale storage capacity**
   - Another flexibility option with Industry and large commercial consumers as potential partners, this procurement will target Industries with sizeable backup capacities, to consolidate backup reserves from 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.
   - ➔ Incentives would be key to not just unlock existing back-up capacity but also to encourage owners to transition from diesel gensets to battery storage for.
3. **Market design that integrates initiatives**
   - Build electricity markets that integrate new and existing resources at least cost
     - more robust day ahead markets,
     - ancillary services,
     - seasonal contracts,
     - capacity markets, etc
   - Enhance learning by doing, e.g. storage manufacturing, to slowly build relevant capacity, incentives and market signals and integrate them into existing structures

7.1.3 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. Setting up an agriculture pumping feeder separation programme for Tamil Nadu
4. Nodal cost assessments for assessing optimum locations of grid battery storage
5. Development of income algorithm for grid battery storage developer to attract private investors and multilateral financiers, and development of pilots
6. Development of pricing structures and overlay of incentives to target participation of BTM captive generation as well as backup capacity in flexibility services
7. Capacity market mechanism to procure reserves, especially seasonal reserves.
8. Last but not least, there is a need for the development of a 'data mission' for Tamil Nadu 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: Case studies

Expanding some of the market tools and mechanisms deployed in these international markets and what they facilitated the targeted market for storage.

AB2514, California – Command and Control, Grid scale and BTM

The California Public Utility Commission (CPUC) ordered the three major investor-owned utility to procure 1.3GW+ of storage by 2020, targets to be met through competitive tenders, for deployment at three interconnection points - transmission connected, distribution-connected, customer-side applications. The mandate also required testing which applications were best suited for utility ownership vs third-party providers. CPUC also ordered the investor-owned utilities, additional 500MW of behind the meter storage

This directive helped break the ice re storage in California, helping utilities develop competency in evaluating size of demand for storage and set targets and signalled the creation of a market to investors, similar to India's announced targets at the Paris COP signalled RE market opening.

SGIP, California – Financial Incentive, BTM

In 2017, the SGIP programme in California was extended with a total budget incentive of $567 million, 80% of which was earmarked for energy storage. Out of this, $391 million was specially reserved for large scale projects, 10kW or bigger and $57 million was reserved for residential projects, <10kW. This programme worked in conjunction with the introduction of **Net Metering 2.0**, along with **Time of Use (TOU) pricing** as well as introduction of **interconnection and energy efficiency fees**.

This incentive programme helped break the operational barrier for storage, especially behind the meter storage by boosting market confidence and lowering cost barriers by providing BTM storage access to additional revenue streams.

Some commercial projects have emerged from this programme such as Stem, which combines fixed payments from customers for energy storage equipment, with fixed capacity payments from the Utility for resource adequacy and variable revenue from wholesale market for energy and ancillary services participation.

Frequency Regulation Market Reg D, PJM – Enabling Environment

The Frequency Regulation Market is supported by FERC's Order 755 which supports market compensation for resources with ability to adjust output or consumption in response to an automated signal, and requires that grid operators compensate them, including fast ramp rate resources according to their actual performance and technical ability. In 2012, PJM split its regulation signal into slow-responding (Reg A) and fast-responding (Reg D).

This new regulation market structure drove most of the energy storage deployment in PJM, where by 2015, about 170MW of energy storage capacity had come online, c.78% of national capacity. This market also led to the set-up flywheel capacities to meet Reg D frequency response.

A later change in the Reg D requirement, revised Reg D gains downwards, eventually crashing the market. A key drawback of this approach was in its singularity of revenue stream and inability of committed resources to draw secondary revenue streams through participation in other markets. Energy Storage capacities, including battery storage and flywheel storage now participate through Ancillary services market or bidding their capacities in PJM's capacity markets.

Resource Adequacy, PG&E – Enabling Environment

In the absence of sufficient market interest, PG&E introduced resource adequacy contracts to meet its grid scale storage requirements. Resource Adequacy is used by load serving entities to procure sufficient capacity resources including reserves to serve aggregated load on a monthly basis. It is a bilateral contract on similar lines to Capacity contracts where the generator receives a capacity payment and needs to be able to sustain maximum output level for four consecutive hours. Lithium ion technology has an advantage due to the way RA criteria are set.

RA is the biggest value driver for energy storage and accounts for 90% revenue for most projects. However, it suffers from a lack of transparent price signals (unlike capacity markets) that can incentivise new builds. While RA benefits from contracts at both the supply and consumer-end, low RA prices and short-term contracts may not be enough to recover capital cost of peaking units.

Tiered Pricing, Time of Use, PG&E – Enabling Environment

Time of Use pricing varies the electricity rates according to hour of use, time of day, season and day type (weekday or weekend/ holiday).

In addition, **Tiered pricing** introduces rates change in steps depending on usage and its baseline varies by season and region. The two can be implemented in conjunction.

Type of volumetric pricing where electricity rates vary according to hour of use, time of day, season, and day type (weekday or weekend/holiday)

At PG&E, all industrial, commercial and agricultural customers are required to be on a TOU plan. Residential customers can choose to be on to time of use plans.

These mechanisms reduce the high cost threshold for storage, by accreting value to the consumer by storing energy during off peak hours and discharging during peak hours, which can reduce both the overall energy consumed from the grid as well as the price paid for the consumption. When combined with Net Metering, storage can be used to discharge into the grid/ local consumption during peak hours, adding additional value.

Hawaii – Multiple Market and Enabling Mechanisms

Hawaii is an Island state and was one of the early adopters of renewable energy, establishing the target for 100% energy from renewables by 2045, through an Act in 2015. It simultaneously also dropped the Net Metering provision that had facilitated the proliferation in must-run roof top solar in the state, but which caused curtailment for Utility scale PV in absence of adequate flexibility resources.

The state then introduced Renewable Dispatchable Generation PPA, providing lump sum payments for right to 'dispatch' energy and rates calculated by estimating 'net energy potential' thus forcing risk sharing between utility and asset owner and eliminating curtailment risk.

This was followed by targeted procurement of storage capacity, co-located with solar by Hawaiian Electric, and subsequently behind the meter storage capacity thus creating signals for storage market investors. The tariffs for distributed energy resources have also been adjusted to reflect Time of Use rates on Gross metering exports. The federal income tax credit that supports solar , has also been made available to storage that gets at least 75% of its charge from on-site solar, improving project economics for investors.

Annex 2: Figures & tables

Figures

Tables

Box

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