# Roadmap for System Integration of Renewables in India's RE rich States

## Volume 3.

## Karnataka Power System Transformation Workshop Report

Report Release Date**: 21 October 2021**

Workshop Date: **19 January 2021**

Workshop Venue: virtual webinar

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# 1. Workshop background

Integrating higher shares of variable renewable energy (VRE) technologies, such as wind and solar PV, in power systems is essential for decarbonizing the power sector while continuing to meet growing demand for energy. Thanks to sharply falling costs and supportive policies, VRE deployment has expanded dramatically in recent years. However, the inherent variability of wind and solar PV power generation raises challenges for power systems operators and regulators. The International Energy Agency (IEA) is working with governments globally on how to prioritize different measures to support system flexibility, identify challenges and implement measures to support the system integration of VRE.

As part of the Clean Energy Transitions Program the IEA has been collaborating with India on system integration of renewables since 2018, when we delivered a national workshop in Delhi with NITI Aayog and the Asian Development Bank, and four regional workshops in Delhi, Chennai, Pune, and Kolkata. Since 2019 the IEA, with the sponsorship of the British High Commission and in association with NITI Aayog, has been organizing a series of state-level Power System Transformation Workshops in Indian states, with the objective to help inform the state governments' actions for system integration of solar and wind. We held three workshops in 2020 and 2021: in Maharashtra (February), in Gujarat (October) and the third workshop on 19 January 2021 in Karnataka as shown in Table 1 below. The Karnataka workshop was held in association with NITI Aayog, Ministry of Power, the Karnataka Government, the British Deputy High Commission Bengaluru and the Centre for Study of Science, Technology and Policy.

| State | Workshop Date | Workshop format | Workshop Report Date |
|---|---|---|---|
| **Maharashtra** | 18 February 2020 | In person | August 2020 |
| **Gujarat** | 7 October 2020 | virtual | February 2021 |
| **Karnataka** | 19 January 2021 | virtual | April 2021 |

Table 1: IEA India Renewables Integration work: timeline

Following the completion of all three workshops, the Renewables Integration in India 2021 report was drafted and published on the IEA[1] and NITI Aayog websites in July 2021. Some of the analysis is also featured in the IEA India Energy Outlook 2020 published in February 2021.

## 1.1 India overview and International Framework for System Integration of Renewables

The share of solar and wind in India's ten renewable-rich states is significantly higher than the national average of 7.5%, and these states are already redefining how their power systems are operated. The most significant renewables integration challenges are in Karnataka (where solar and wind account for around 30% of annual electricity generation), Rajasthan (20%), Tamil Nadu

[1] https://www.iea.org/reports/renewables-integration-in-india

(19%) and Gujarat (13%). These states with ambitious targets, are experiencing system integration challenges ahead of most countries internationally. Therefore, the IEA Clean Energy Transition Program (CETP) focusses on analysis of the RE integration challenges and opportunities for flexible solutions in these key states through the State level workshops being organized in the year 2020 and 2021.

Instead of focusing on all kind of renewables, the following analysis and this report focusses on VRE because the amount of VRE on the system is one of the key drivers of renewables integration challenges. We also take into account the impact of other renewables, namely hydro and bio-energy, noting that these normally impact system integration of renewables positively, as they are flexible forms of power generation.

The IEA system integration of renewables framework categorizes renewable integration into six phases, with suggestions on how renewables integration can be successfully managed in each Phase, as seen in Figure 1 below. Various phase-specific challenges can be identified in the deployment of VRE, and this framework can be used to prioritize different measures to support system flexibility. These phases are described in detail (IEA, 2018) and recent examples and insights are highlighted (see IEA & 21CPP, 2019).

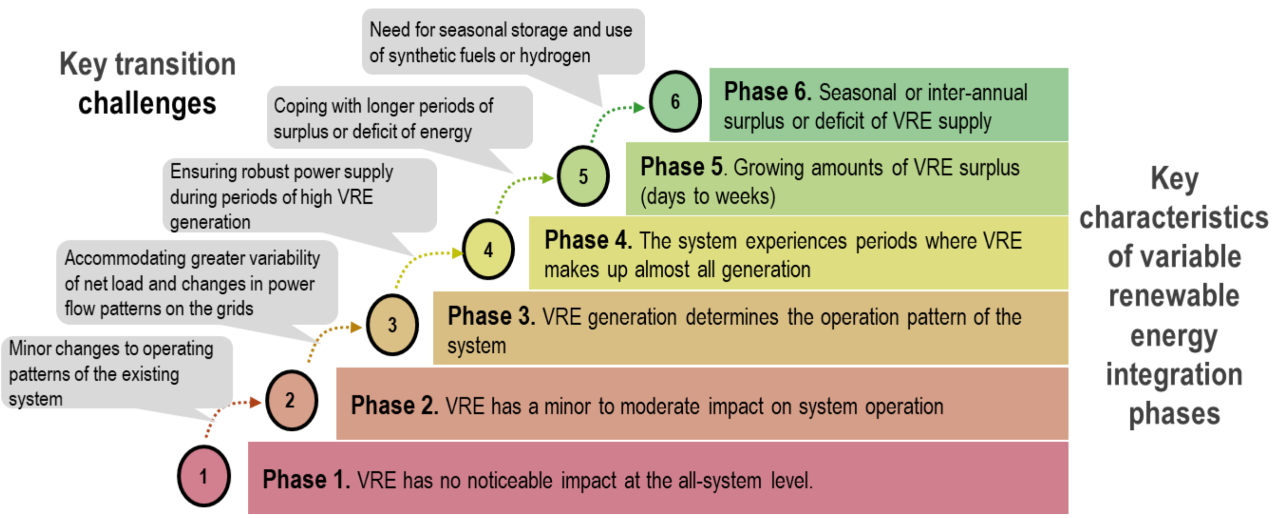


Figure 1: Phases of System Integration of Renewables, Source IEA

As seen in Figure 2 below, some Indian States like Karnataka and Tamil Nadu are already in phase 3; and are already facing challenges to integrate high shares of variable renewables. The workshop highlighted what the state of Karnataka may learn from the international experiences of high VRE countries/regions such as UK, Ireland, US States of Texas and California, and South Australia and how these learnings can fit into the Karnataka system transformation process. These lessons can help Karnataka to leapfrog some of the integration challenges.

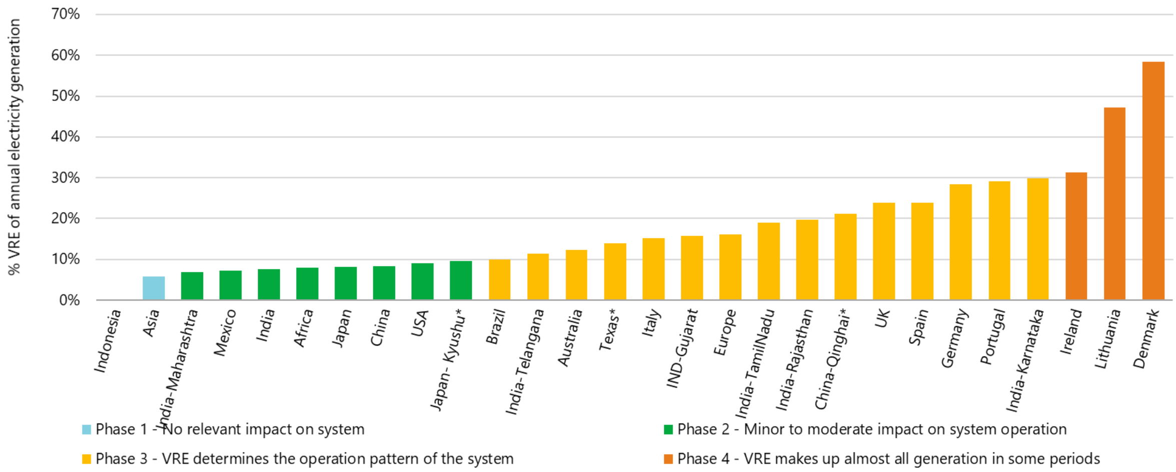


Figure 2: Countries and Regions in Phases of Renewables Integration
Source IEA analysis, 2019 data (*indicates 2018 values)

## Connecting RE Phases with flexibility resources at different time-scales

The flexibility of a power system refers to the extent to which a power system can modify electricity production or consumption in response to variability, expected or unforeseen. Flexibility can therefore refer to the capability to change power supply or demand of the system as a whole or a particular unit. Flexibility can be provided at different time scales as highlighted in Figure 3. According to IEA phase assessment framework, different flexibility resource types acting at different time scales will be more pronounced and need to ramp up at different phases of renewables integration.

| Flexibility type | Ultra short term flexibility | Very short term flexibility | Short term flexibility | Medium-term flexibility | Long-term flexibility |
|---|---|---|---|---|---|
| **Timescale** | Subseconds to seconds | Seconds to minutes | Minutes to days | Days to weeks | Months to years |
| **Issue** | Ensure system stability (voltage, transient and frequency stability) at high shares of non-synchronous generation | Short-term frequency control at high shares of variable generation | Meeting more frequent, rapid and less predictable changes on the supply/demand balance | Addressing longer periods of surplus or deficit of variable generation | Balancing seasonal and inter-annual availability of variable generation |
| **Most relevant integration Phase and example regions** | Phase 4<br>Several VRE rich states by 2025 | Phase 3<br>Gujarat, Karnataka, Tamil Nadu in 2020 | Phase 2<br>India as a whole, Maharashtra in 2020 | Phase 4 | Phase 5<br>Phase 6 |

Figure 3. Flexibility at different time-scales and Phases
Source: IEA analysis, 2020

In Karnataka, due to the state being in Phase 3 today, the system operation flexibility need is greatest for resources that provide flexibility from *minutes to hours* (to overcome very short-term variability of solar and wind) and there will be an increasing need for *minutes to days* and *seconds to minutes* flexibility with the expected increase of solar generation. Later, as Karnataka reaches

Phase 4, more focus on ultra-short-term flexibility capabilities will be required in order to provide flexibility within seconds, as well as flexibility capabilities within the days of the week. Then, in Phase 5 and 6 the focus can shift towards flexibility over months to years, often referred to as seasonal flexibility.

The type of resources that can typically provide flexibility in these timeframes (and associated Phases) are presented in detail in Figure 4 below. These power system flexibility enablers can be VRE and conventional generation technologies, grid infrastructure, storage assets, demand-side resources and sector coupling. The following chapters of this report address the flexibility enablers most relevant for Karnataka.

| Flexibility timescale / Flexibility resource | Ultra-short term (subseconds to seconds) | Very short term (seconds to minutes) | Short term (minutes to hours) | Medium term (hours to days) | Long term (days to months) | Very long term (months to years) |
|---|---|---|---|---|---|---|
| **State-of-the-art VRE** | Controller to enable synthetic inertia; very fast frequency response | Synthetic governor response; AGC | Downward/ upward reserves; AGC; ED of plants including VRE | ED tools; UC tools; VRE forecasting systems | UC tools; VRE forecasting systems | VRE forecasting systems; power system planning tools |
| **Demand-side resources** | Power electronics to enable load shedding | Demand-side options including electric water heaters, electric vehicle chargers, large water pumps and electric heaters; variable-speed electric loads | Air conditioners with cold storage and heat pumps; most equipment listed under very-short-term flexibility | Smart meters for time-dependent retail pricing | Demand forecasting equipment | Demand forecasting equipment; power-to-gas |
| **Storage** | Supercapacitors; flywheels; battery storage; PSH ternary units | Battery storage | Battery storage; CAES; PSH | PSH | PSH | PSH; hydrogen production; ammonia or other power-to-gas/liquid |
| **Conventional plants** | Mechanical inertia; generation shedding schemes | Governor droop; AGC | Cycling; ramping; AGC | Cycling; quick-start; medium-start | Changes in power plant operation criteria | Retrofit plants; flexible power plants; keeping existing generators as reserve |
| **Grid infrastructure** | Synchronous condensers and other FACTS devices | SPS; network protection relays | Internodal power transfers; cross-border transmission lines | Internodal power transfers; cross-border transmission lines | Control and communication systems to enable dynamic transmission line ratings; WAM; HV components such as SVC | Transmission lines or transmission reinforcement |

Notes: AGC = Automatic Generation Control; CAES = compressed air energy storage; FACTS = flexible alternative current transmission system; SPS = special protection schemes; SVC = static var compensator; WAM = wide area monitoring system.

Figure 4. Flexibility solutions offered at different time-scales. Source: IEA, 2018

## 1.2 Karnataka state overview

The State of Karnataka has a total installed capacity of 30 GW with renewable energy (RE) contributing to about 40% in the total energy mix. The conventional generation capacity of Karnataka includes 9.5 GW of coal, 0.9 GW of nuclear and 0.4 GW of gas. It also has 3.6 GW of hydro power generation capacity. Karnataka has been a pioneer in the deployment of RE with over 15 GW[2] of commissioned capacity as on 30$^{th}$ November 2020, with half of the RE capacity coming from solar power and one-third from wind power[3]. With this, Karnataka has already achieved the 11 GW solar and wind target allocated to the state from the national targets of 175 GW by 2022. In terms of installed grid connected RE generation, Karnataka ranks first in India followed by Tamil Nadu and Gujarat.

At present, the State of Karnataka has a high share of VRE deployment (40% of total energy mix). In Karnataka, 30% of annual generation comes from VRE generation, this is due to lower solar and wind capacity factors (around 15% to 17% and 30%, respectively) and curtailment of renewables, a key system integration challenge in the state.

According to the Karnataka Renewable Energy Development Ltd (KREDL) targets, the share of solar capacity could increase to 26% and the share of wind capacity to 28%, while the share of coal would fall to 30% by 2030. The state has an additional 9 GW of solar and wind in the pipeline by 2030. Still, the capacity targets will translate to lower shares in annual generation terms due to the low capacity factors of solar and wind.

The increasing annual share of solar and wind energy generation in Karnataka up from today's 30% will redefine how the state's power system should be organized, planned and operated. System integration challenges are already pronounced when we look at the daily snapshot of power generation as shown in Figure 5. While solar and wind can meet over 60% of the daily generation today, this number is expected to increase to close to 100% before 2030. This means that before 2030 Karnataka is expected to see challenges that have not yet been experienced by any Indian state today.

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[2] https://npp.gov.in/public-reports/cea/monthly/installcap/2020/NOV/capacity2-Southern-2020-11.pdf
[3] https://kredlinfo.in/

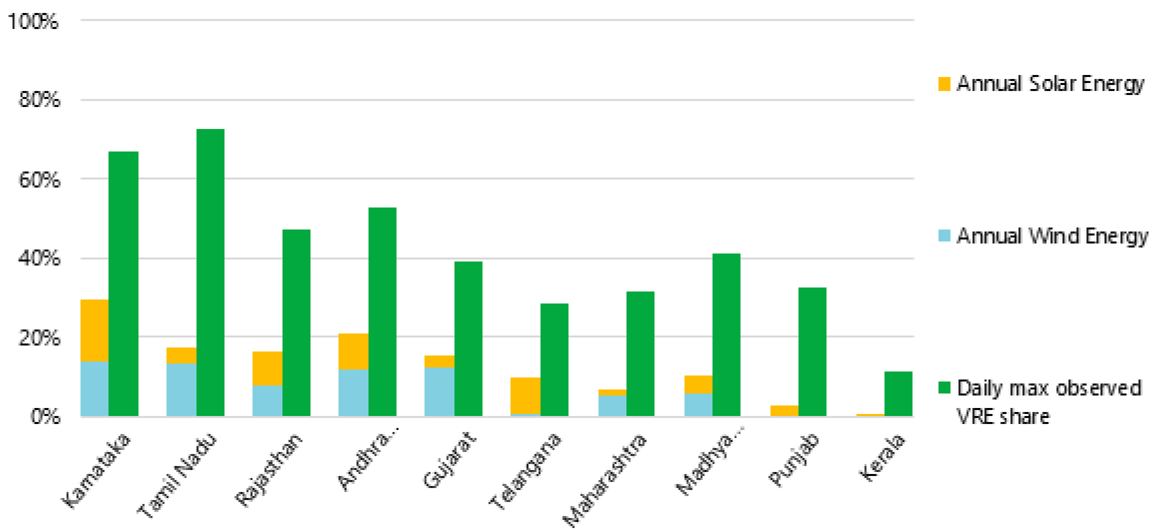


Figure 5. Yearly average and daily maximum solar and wind share in generation in RE rich States of India

Source: IEA analysis, 2020,

CEA (2019d), actual VRE electricity generation form April 2018-March 2019, MNRE (2019), VRE Installed Capacity as on 31st March 2019.

Daily max observed VRE: https://eal.iitk.ac.in/

2025 estimate, Maharashtra demand projection: https://mhsec.mahadiscom.in/.

# 2. Outcomes of the Karnataka Workshop

## 2.1 The key RE integration challenges and solutions in Karnataka

The Karnataka workshop on 19 January 2021 was held in association with the Ministry of Power, the Karnataka Government, NITI Aayog, the Centre for Study of Science, Technology and Policy, and the Centre for Energy Regulation, IIT Kanpur. The workshop was a public-door virtual event with 250 registrations including more than 100 key local Indian and Karnataka State experts, and more than 10 international power sector stakeholders shared ideas and identified RE integration related challenges and opportunities on a single platform. The objective of the workshop was to discuss and deliberate on the plan for grid integration of high shares of wind and solar in Karnataka, while learning from international perspectives on addressing challenges of flexibility options that could ensure cost-effective system planning and operation.

The three workshop sessions topics included:

1. Opening and high-level context session
2. Karnataka's power system in light of high shares of solar and wind
3. International perspective on challenges and opportunities for high shares of solar and wind

Prior to the workshop, IEA undertook a series of analyses and consultations with local stakeholders which for the basis for developing the agenda, trying to focus on the most important RE integration questions of relevance to Karnataka State. In line with the identified topics, presentations were made by KPTCL, BESCOM, CSTEP, NITI Aayog, ARUP, LBNL, New York State Public Service Commission, India Energy Exchange, and Australia's Energy Security Board with presentations available for download at the IEA workshop webpage. The full list of presenters is provided in Annex 2.

Following each session, the participants responded to interactive polling questions. Based on the pre-workshop analysis, the workshop presentations and the results of the polling questions, we have listed below the key institutions, challenges and solutions relevant to the system integration of renewables in the state.

Firstly, the workshop participants thought that regulators (KERC) are the key institutions for transition towards more renewables, followed by policymakers, the private sector, DISCOMs (BESCOM), the transmission utility in Karnataka, responsible for planning and operations – KPCTL,.

Secondly, we found that significant challenges exist for reaching the Karnataka 2030 renewables targets. The most important challenges as seen by Karnataka stakeholders are the forecast of solar and wind, transmission challenges, technical challenges such as system strength and voltage issues, demand forecast, curtailment of solar and wind and distributed energy resources (rooftop solar, EVs, etc.). The workshop presentations therefore covered these topics, as shown in Table 2 alongside further in-depth analysis.

| Key Karnataka RE integration challenges identified<br><br>In order of importance and poll ranking | Covered in workshop by key organisations |
|---|---|
| Transmission challenges | Yes, KPTCL, CSTEP and IEA presentations |
| Frequency and voltage issues | Yes, KPTCL and IEA presentation |
| Curtailment of solar and wind | Yes, KPCTL, CSTEP, LBNL and IEA presentation |
| Inertia, system strength | Yes, KPTCL and IEA presentation |
| Forecast of solar and wind | Yes, KPTCL presentation |
| Forecast of demand | Yes, KPTCL presentation |
| Distributed energy resources: rooftop solar, EVs, etc. | Yes, CSTEP, LBNL and ARUP presentation |
| Increasing consumer prices | Yes, Australian case study presentation |
| Blackouts, outages | Yes, KPTCL presentation |

Table 2. Karnataka solar and wind integration challenges, *Source: IEA analysis*

Thirdly the workshop and the in-depth IEA analysis concluded that innovative technical and policy, market and regulatory solutions are available both locally and internationally to enable system friendly ramp-up of renewables in Karnataka. The most important solutions are demand response, transmission planning, regulatory reforms, flexible coal power plants, cross-border RE trade, tariff reforms and energy storage. The workshop presentations therefore covered these topics (Table 3) alongside further in-depth analysis presented in Chapter 3 and Chapter 4 of this report.

| Key Karnataka RE integration solutions identified<br><br>In order of importance and poll ranking | Covered in workshop by key organisations |
|---|---|
| Energy storage incl. batteries and pumped hydro | Yes, KPTCL, IEA, LBNL and ARUP presentations |
| Transmission investment | Yes, KPCTL, IEX and CSTEP presentations |
| Regulatory reforms | Yes, KPTCL and IEA presentations |
| Demand Response | Yes, CSTEP and IEA presentations |
| Flexible coal plants | Yes, KPTCL and IEA presentation |
| Flexible solar and wind | Yes, IEA and CSTEP presentation |
| Flexible gas plants | Yes, IEA presentation |
| Tariff reforms | Yes, ARUP, NYSPUC and IEA presentation |
| New ancillary services | Yes, KPTCL presentations |
| New technologies: hydrogen, EVs... | Yes, IEA and ARUP presentation, sector coupling |
| Hydro plants | Yes, KPTCL and IEA presentations |

Table 3. Karnataka solar and wind integration solutions
Source: IEA analysis

## 2.2 The key takeaways from the Workshop Presentations

Following is a short summary of the key takeaways from the workshop presentations covering the key topics. The workshop has been recorded and the recording, agenda and presentations available publicly at the workshop webpage.

### Increasing share of solar and wind in Karnataka driven by RE policies and targets

Karnataka contributes 30% to the national level renewables basket and is one of the front runners of the Climate Efficient Initiative. It already has a large share of renewables in its generation mix (~47%). The state has already crossed the 11 GW RE target of the Government of India for 2022 by generating 15 GW of RE in 2021, as per KREDL[4] (Karnataka Renewable Energy and Development Limited). Recently, it has moved from deficit to surplus state with the capability of meeting agricultural demand during daytime. Key policy schemes by KREDL include:

[4] https://kredlinfo.in/

1. Land Owner Farmers Scheme (LOFS) for 1 to 3 MW solar projects under the Solar Policy 2014-2021,
2. Promoting intra-state business model to achieve additional 6 GW of RE by 2022, and
3. Policy for re-powering of old wind power plants, gross metering and tariff management. (For more details refer to KPTCL presentation on the workshop webpage).

CSTEP's study found that the power generated at critical instants in 2030 could be well in excess of regional demand, necessitating the upgrade of inter-regional transmission corridors to handle export of power of up to 50 GW. Significant need for intra-regional transmission upgrades was found, primarily at 220 kV RE injection points and transmission lines, beyond existing upgrade plans. Expected investment required for transmission upgrades is around USD 1.3 billion by 2030.

### Power trade to support RE integration in Karnataka

Karnataka has transformed itself into a RE surplus state with a seven-time increase in RE capacity in the last 10 years. Power trading is shaping profitable markets in the state with consumer preference shifting towards green energy. The Karnataka DISCOM's are important players as both buyers and sellers on the day-ahead and real time markets. Indian Energy Exchange (IEX) noted that the green term-ahead market (G-TAM) and the real time market (RTM) are critical for large scale RE integration. The RTM market launched in 2020 has proven useful for managing forecasting deviation, and a snapshot of buyers and sellers, transactions and prices is shown in Figure 6.

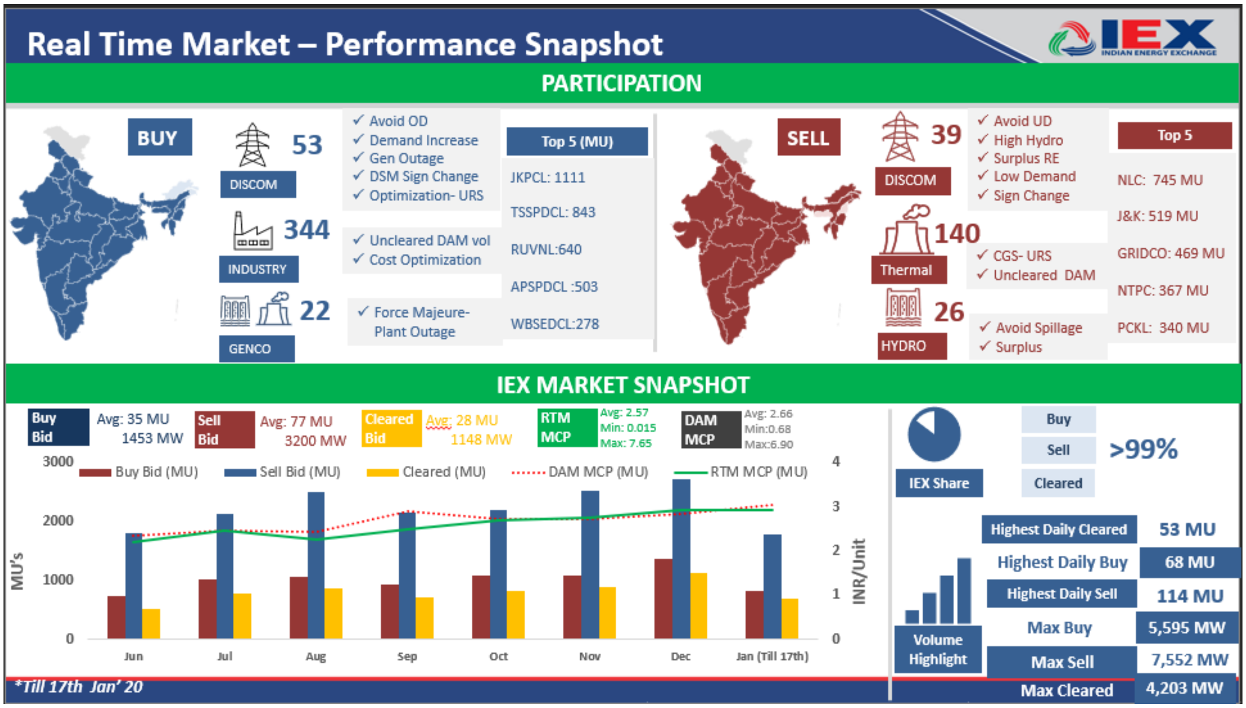


Figure 6. India Energy Exchange, 2020 snapshot of real time markets

The LBNL power sector model further showed significant electricity trade in the southern region of India alongside the Karnataka intra-state transmission lines by 2029, illustrated in Figure 7, which had complementarity with energy storage planning.

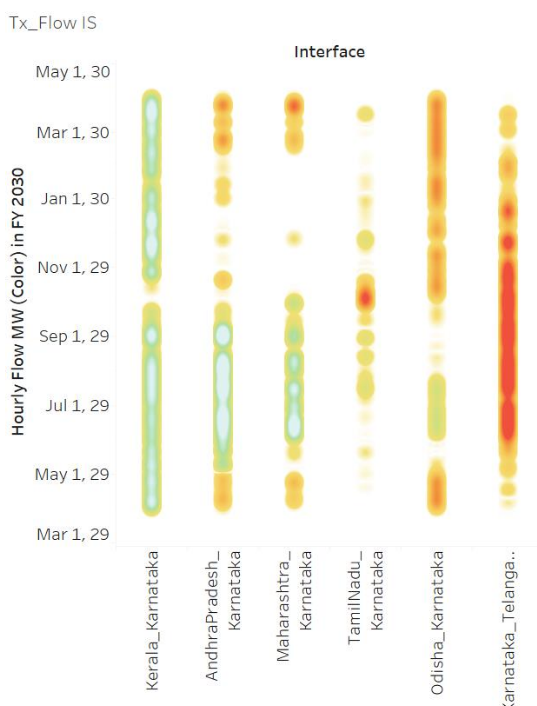


Figure 7. Inter-state electricity trade for Karnataka becomes crucial by 2029, LBNL analysis

## Curtailment of solar and wind

KPCTL specified that the state is addressing generation and load management issues including: (1) managing intraday dynamic changes of RE generation, (2) managing Seasonal variation in RE Generation, (3) need for high Conventional Generation reserve, (4) thermal power plants are to be kept on bar to meet non-solar peak demand, (5) under-utilization of thermal generation, and (6) voltage management issues. Additionally, by 2030 CSTEP in their model observed more curtailment during high-RE scenarios which will increase the scope for more energy storage projects.

In Karnataka in 2019 and 2020, renewables power plants (particularly solar and wind) have experienced events with the state load dispatch centre announcing curtailment[5] of 10% up to 25% of renewables generation (both wind and solar) for midday hours in the State of Karnataka in the month of June, July, August and September owing to reduced demand and in the interest of grid security

For investors, the increasing solar and wind curtailment and lack of related policies are key concerns. According to IEA-CEEW analysis, for solar PV projects the investor's internal rate of return would decline by 160 basis points for every 2.5% production loss per year. The expectation of future curtailment can therefore significantly increase solar power purchase costs.

In 2020, influenced by the coronavirus (Covid-19) power sector investments in India fell by USD 10 billion year-on-year to USD 39 billion, including a decline in solar and wind investments. Improving investor confidence will be an important factor in the coming years as India will need to increase power system investments twofold by 2026 in the STEPS or threefold in SDS, relative to 2020 levels.

Internationally some level of curtailment is present in most of the high solar and wind countries, typically up to 3% of annual solar and wind output – according to analysis presented in IEA Renewables Market Report 2020. China sustained high levels of dispatched-down VRE from 2011 to 2017 (7-20%), reaching an absolute historical high at almost 50 TWh in 2016, then the share of solar and wind curtailment dropped to less than 4% by 2019. Even though the total amount of curtailed VRE electricity overall has increased in the United States, Germany and Italy since 2017, the share of VRE curtailment has remained stable at 1-3%, which means that most systems have been able to evolve to accommodate increasing VRE generation as the capacity expanded. In contrast, record curtailment levels were reached in California in 2020, with the system operator (CAISO) curtailing over 318 GWh in April (7% of VRE output) – 67% more than in 2019 – due to falling demand (8% decline) as a consequence of both the Covid-19 pandemic and newly added solar and wind capacities.

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[5] https://kptclsldc.in/recurtail.aspx

Going forward, the CSTEP analysis highlighted in Chapter 3 of this document concludes that by 2030 the high RE scenario would result in significant solar and hydro curtailment in Karnataka. The renewable integration solutions presented in Chapter 4 of the present document provides considerations for Karnataka government that can minimize future curtailment in the state.

### Transmission challenges and solutions

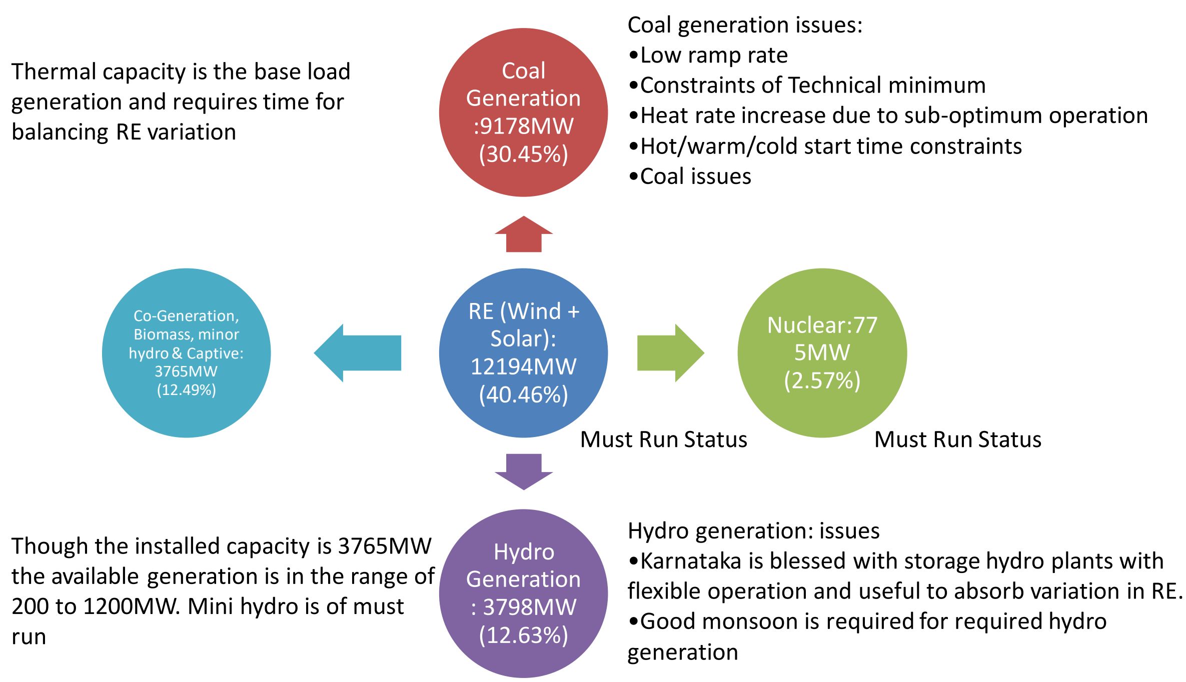
KPTCL highlighted that currently Karnataka only faces some localized system integration challenges on the power system. The KPCTL transmission expansion plan is designed to facilitate the planned RE deployment and power trade.

CSTEP presented an innovative web-based interactive transmission planning portal named Darpan that will aid in real-time transmission line planning.

To promote further research required for RE grid integration, such as higher resolution grid simulation studies, CSTEP is hosting all the modelling elements used for the study, along with the results, in a geospatial web-based visualisation portal[6], freely accessible to all.

### System strength and voltage challenges and solutions

Today, Karnataka already faces significant RE integration challenges, including very high seasonal variation in solar and wind generation, voltage management issues, underutilization of coal power plants, increasing ramp rate requirements while existing coal feet has low ramp rates, technical minimum constraints and high start-up costs, some of which is summarised in Figure 8.




[6] http://darpan.cstep.in/highre/

Figure 8. System operation challenges as defined by KPTCL on load management due to accelerated RE generation

IEA highlighted that international experience shows that other systems with declining inertia manage the transition towards higher shares of solar and wind with technical solutions such as the deployment of synchronous compensators and synthetic inertia provided by grid-forming converters (further details in IEA workshop on Technical Secure Integration of Large Shares of Converter-based Power Sources, March 2020[7]).

KPTCL also highlighted that adoption of new technologies and rapid installation of new power system management tools will be required, including grid ancillary services, grid supporting smart technologies, and the full use of digitization opportunities, for example STATCOM, WAMS and data analytics. Furthermore, they highlighted the ongoing improvement of grid code standards.

### Distributed solar challenges

The existing Karnataka policies incentivize significant distributed solar deployment. BESCOM was ranked first in the State Rooftop Solar Attractiveness Index – SARAL by the GoI.  Innovative solutions by KERC included an agile business model, web-based tools to assess rooftop solar potential, solar helpdesks with customer support system and a centralized solar billing centre to process gross metering and net metering bills above Rs. 1 lakh. Challenges included decline in BESCOM revenue as net-metering was mandated for commercial and industrial consumers; and most of the HT consumers opting for open access. Initially, to encourage the rooftop solar among the consumers the State Commission has allowed solar capacity maximum up to 1MW under net-metering. As the Solar Rooftop tariff was high (Rs.9.56/- per unit), many applications flooded BESCOM for installation of solar on big roofs such as in poultry farms, godowns, etc. BESCOM mentioned that with the increase in rooftop solar they see challenges with reactive power and impact of harmonics.  Monitoring of solar generation data is expensive for small rooftop plants.

### Flexibility from demand response

The key flexibility driver for Karnataka is the high expected penetration of renewable generation in the energy mix by 2030. KPTCL and BESCOM both highlighted that demand side management, including agricultural demand shifting, space cooling and industrial load management are already important grid balancing tools today, and this is expected to be even more important in the future. BESCOM further highlighted Karnataka as the 'Silicon Valley of India', due to its high-tech industrial clusters which can play a critical role in demand response through building energy efficiency measures and heat-stress management plans.

### Flexibility from conventional generation

While Karnataka leads the country in solar deployment at over 5.2 GW of solar installation, the stat plans to further expand solar PV, including through rooftop installations. KPTCL noted that

[7] https://www.iea.org/events/technical-secure-integration-of-large-shares-of-converter-based-power-sources

the state could therefore experience a ramping need of up to 30% of peak demand by 2030 from its current levels of 14%, as well as potential excess generation during the day. In addition, CSTEP's model showed that by 2030 there is limited flexible capacity available from hydro power plants due to agricultural demand and limitation during monsoon flows. The load factor requirement for the thermal generation of the state was discussed to be a critical flexibility need. Without interstate transfers the thermal load factor could fall by 30%.

LBNL also stressed that flexibility resources will play a crucial role in system balancing in 2030 with load shifting and energy storage providing diurnal balancing, while gas provides seasonal balancing.

### Flexibility from Energy Storage

The international example of UK was presented by ARUP to highlight that, similarly to Karnataka, UK has a large historical hydro power plant fleet. These power plants played an important role for balancing the power system providing flexibility at a few minutes notice for a long term duration. With the increase of wind and solar, however the system operator started to experience increasing sudden frequency volatility that required a reserve that provides flexibility within seconds, with a very fast response time. Pumped hydro was unable to provide this type of service. The 2016 tender by the system operator provided a long-term (4 years) revenue stream for several new battery storage facilities to provide these fast frequency services. As result of ongoing market opportunities for batteries, the UK is the market leader for battery storage deployment in Europe with over 800 MW, followed by Germany with over 500 MW. Batteries in the UK in 2020 can actively participate in day ahead markets, intraday markets and imbalance markets. Additionally, they access revenues from ancillary services markets, capacity markets and, when placed behind the meter, from time of use rates and by avoiding network charges. The conclusion and recommendation for Karnataka is that to introduce battery storage in the state it is advisable to start with a policy than can provide long term (over 4 years) revenue streams for the first battery investors and then move towards providing shorter term services/products in the markets.

LBNL stated that by 2030, around 250 GWh of energy storage are found to be optimal with an approximate 10% average daily renewable generation. Their analysis showed that for up to 8 – 10 hours/day of storage, battery storage is more cost effective than pumped hydro. It also showed that by 2030, 4 – 6 hours of energy storage are cost-optimal for diurnal balancing (see Figure 9). They found that LCOE of solar + co-located battery storage was around Rs 3.5/kWh for 30% storage by 2025.

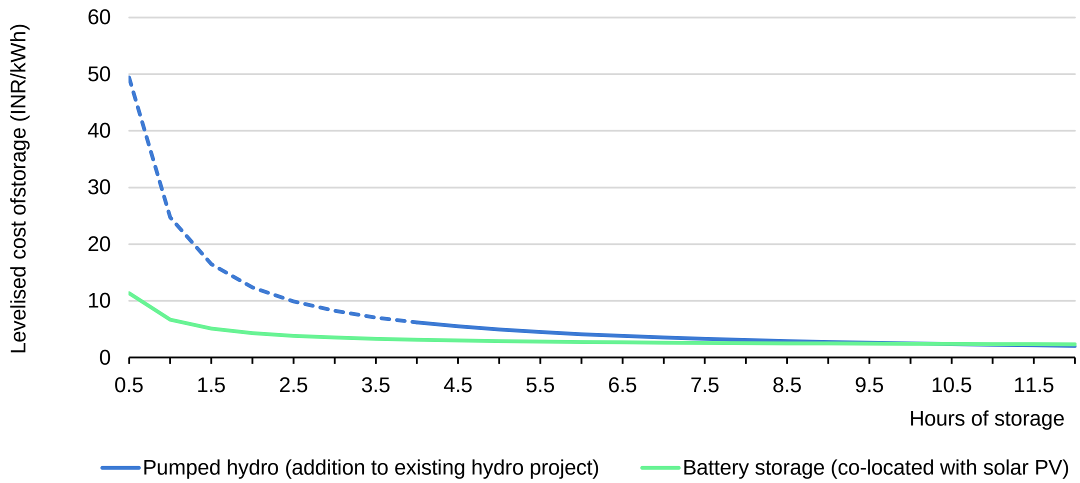



Figure 9. Levelised cost of storage – pumped hydro and battery storage in 2025
Source: Reproduced with permission from Abhyankar et al, 2021 (forthcoming).
Note: Very low storage durations for pumped storage hydropower given by the dotted line are illustrative only, as PSH projects typically have around 8 hours storage or higher.

Karnataka should avoid building new coal assets, however, as they could exacerbate the problem of stranded assets. LBNL strategised a combination of increased RE capacity (over 450GW) with a set of frequency regulation additions: 30 to 60 GW of energy storage, 60 GW of load shifting, flexible operation of the 25 GW of gas, an addition of close to 140GW of new inter-state transmission systems, and implementation of market-based economic dispatch (MBED). An appropriate regulatory framework for energy storage is needed to capture its full value that is not limited to avoiding inefficient thermal investments, but also ensures energy arbitrage opportunities for shifting the energy demand within a day/week and ancillary services for managing the system ramps, among others.

### Ongoing Regulatory reforms

RE policy implementation is highly supported by local players. The implemented Renewable Management Centre is an important tool for RE integration.  The Karnataka regulator is currently considering to create a market for battery storage and provide more flexibility through other initiatives such as solarisation of agricultural feeders and hybrid solar-wind projects.

Karnataka officials are concerned about the role of existing coal-fired power plants in the future. On the one hand, with ambitions to supply more generation from renewables technologies, coal plants are expected to operate less, which leads to reduced revenues. At the same time, in order to operate flexibly and meet stricter emissions standards, some coal plants in some states may also require further investment. Government officials are also concerned that historical dependence on long-term power procurement contracts as the tool for ensuring capacity adequacy create an economic burden by locking in long-term fixed capacity payments for coal power plants.

The BESCOM annual financial model (presented at the workshop) showed the cost per unit of solar power projects is on a decreasing trend year-by-year, and that distribution licensees are eager to purchase renewable power. BESCOM presented innovative solutions to support consumers with the uptake of rooftop solar. BESCOM's revenue has been declining due to net metering of rooftop solar consumers and due to EHT/HT consumers moving to open access.

# 3. Results of the CSTEP power system modelling study

## 3.1 Southern India regional transmission study

CSTEP conducted a transmission planning study[8] to understand the impact of RE addition to the Southern Region grid for 2022 and 2030. A detailed electrical model of the grid as of 2030, based on current plans, was built and validated with SCADA measurements. The model was disaggregated to the level of the individual 220 kV transmission substations and transmission lines (including higher voltages) and involved around 900 substations in all.

Geospatial analysis of viable land parcels to install further solar and wind capacity showed around 188 GW of potential wind capacity and 329 GW of solar capacity. To meet 2030 demand without proposing new thermal capacity (beyond existing plans), 34 GW of additional solar and 18 GW of additional wind were added to the electrical model of the Southern Region, bringing the total installed capacity to 60 GW and 48 GW respectively.

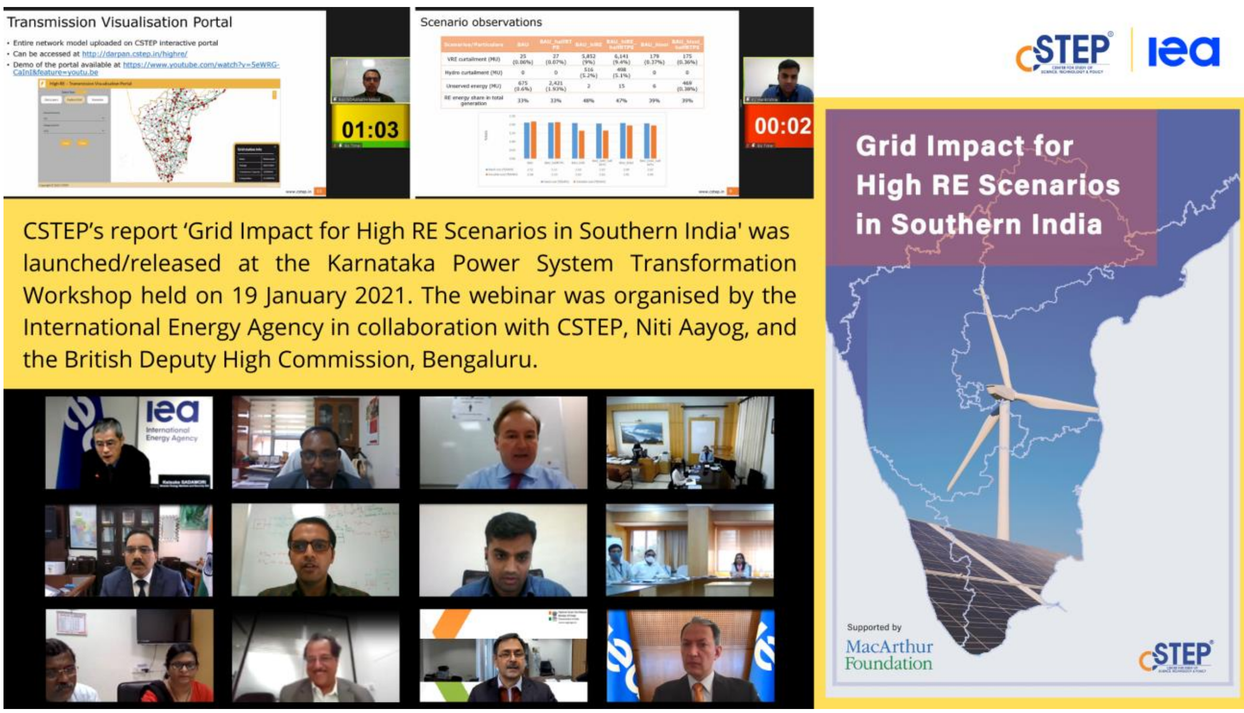



Figure 10. Launch of CSTEP Transmission study at the Karnataka workshop on 19 January 2021

The study found that the power generated at critical instants in 2030 could be well in excess of regional demand, necessitating the upgrade of inter-regional transmission corridors to handle exports of power to the tune of 50 GW. Significant need for intra-regional transmission upgrades was found, primarily at 220 kV RE injection points and transmission lines, beyond existing

[8] https://cstep.in/drupal/node/1424

upgrade plans. The expected investment amount required for transmission upgrades was around USD 1.3 billion by 2030.

To promote further research required for RE grid integration, such as higher resolution grid simulation studies, CSTEP is hosting all the modelling elements used for the study, along with the results) in a geospatial web-based visualisation portal.

## 3.2 Karnataka power system model with high RE share in 2030

Karnataka, being one of the leading state in renewable energy by installed capacity, CSTEP explored the opportunities for higher RE share, optimal energy mix and its effect on the production cost for 2030.

CSTEP used open source software GridPath for production cost analysis. State thermal plats were modelled at unit level, hydro at station level and only state share from central generating stations (CGS). The generator specific technical parameters were collected from various documents from the Central Electricity Authority (CEA), Power System Operation Company Ltd (POSOCO) and Regional and State utility documents.

Hourly power profiles for solar plants were generated using CSTEP's in-House CSTEM PV tool and wind power profiles were generated using NREL's System Advisor Model (SAM). Inter-state transmission capacity with its thermal limits were modelled in order to capture CGS share from neighbouring states. Nuclear plants were modelled as always committed generators with 90% as their minimum generation level. In order to capture agriculture load shift from night to day, a recent load profile for 2019-20 was collected from state load dispatch centre and the same pattern was extrapolated to the study year as per CEA's 19th Electric Power Survey report.

Three different scenarios were analysed with different generation capacities for 2030. The installed capacity considered for scenarios is shown in Table 4.

| Scenario/ Installed capacity (MW) | Business As Usual (BAU) | BAU_Half RTPS | BAU_High RE | BAU_High RE_Half RTPS | BAU_High Solar | BAU_High Solar_ Half RTPS |
|---|---|---|---|---|---|---|
| State thermal | 6,100 | **5,260** | 6,100 | **5,260** | 6,100 | **5,260** |
| CGS share | 5,934 | 5,934 | 5,934 | 5,934 | 5,934 | 5,934 |
| Gas | 370 | 370 | 370 | 370 | 370 | 370 |
| Hydro | 3,782 | 3,782 | 3,782 | 3,782 | 3,782 | 3,782 |
| Solar | 9,386 | 9,386 | **14,650** | **14,650** | **14,650** | **14,650** |
| Wind | 9,820 | 9,820 | **15,940** | **15,940** | 9,820 | 9,820 |
| PHES | 3,200 | 3,200 | 3,200 | 3,200 | 3,200 | 3,200 |
| RTPS retirement | No | **4 x 210** | No | **4 x 210** | No | **4 x 210** |

Table 4: Installed power generation capacities in different scenarios, 2030
Source: CSTEP analysis

All the existing and proposed conventional plants are considered as per the state utility plans, and the solar and wind allotted capacities are considered as per the state renewable development agency targets. For high RE and high solar scenarios, solar and wind projections for year 2029-30 are proposed to meet national target of 450 GW in proportion with the state target of 175 GW for year 2021-22. For all three different scenarios, an additional case is analysed with retirement of state's first Raichur Thermal Power Station 1-4 units, to analyse this effect on the generation mix.

The annual generation dispatch stack for BAU and BAU_High RE scenario are plotted in Figures 11 and 12. It is observed that the state experiences peak demand in summer months (February to April) and off-peak demand in October. The generation from wind is high during the monsoon season (June to August) and the generation from solar is high during the summer season.

In the BAU scenario, significant unserved energy can be seen during peak demand season, suggesting need for additional generation capacity to meet state demand projections. However unserved energy is negligible in in BAU_High RE scenario, due to addition of more solar and wind capacity.

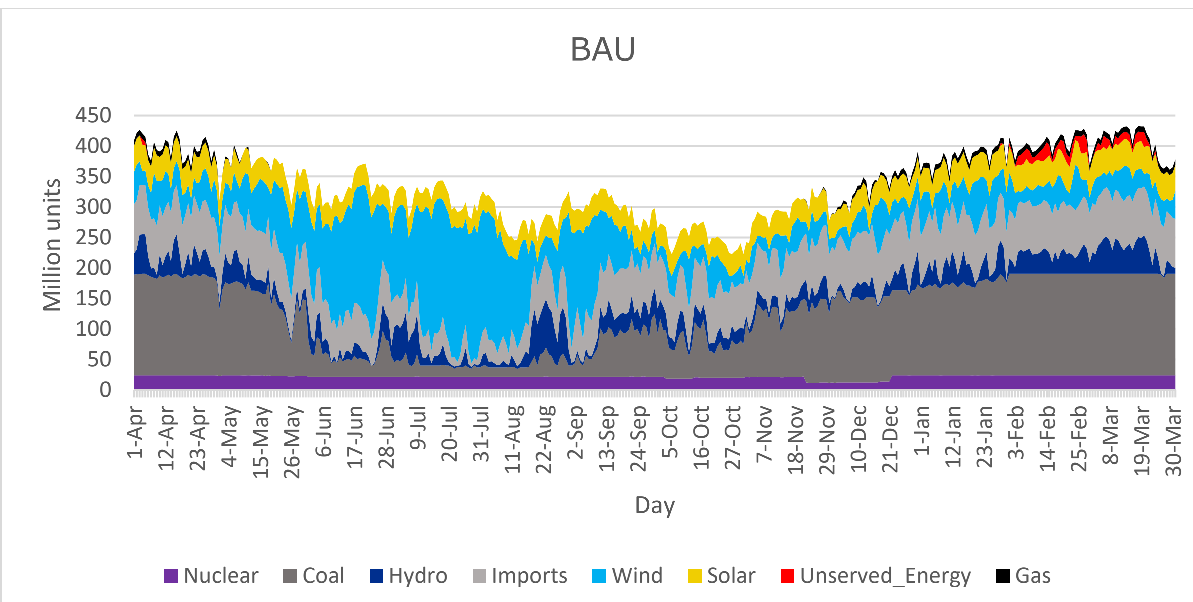



Figure 11: Annual generation dispatch stack for BAU scenario, 2030
Source: CSTEP analysis

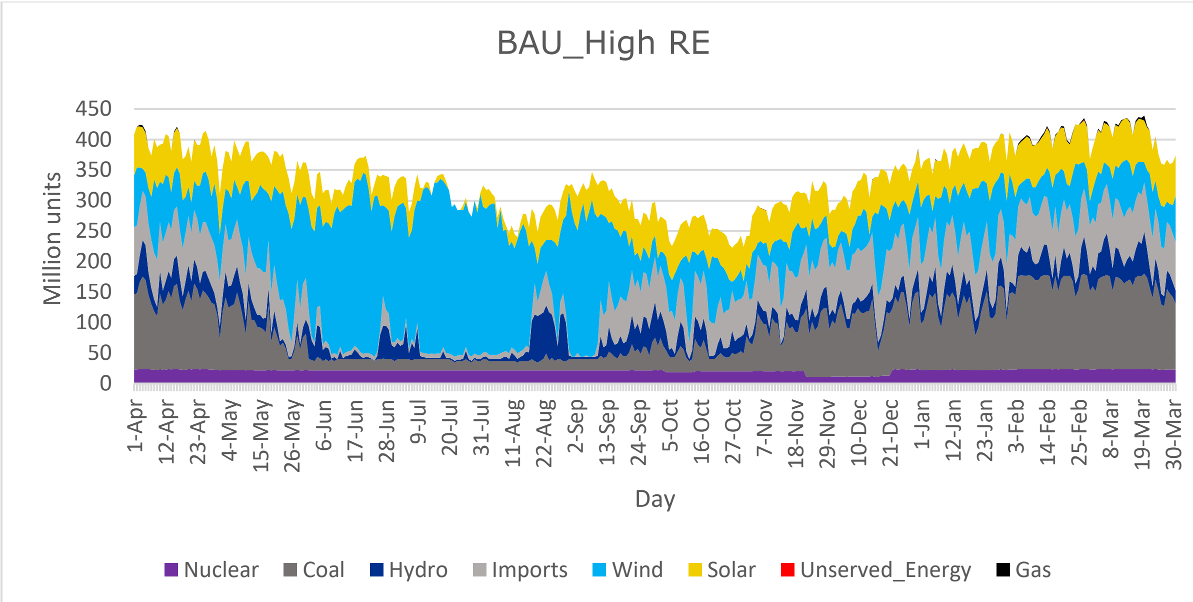



Figure 12: Annual generation dispatch stack for BAU_High RE scenario, 2030
Source: CSTEP analysis

Plotted below are some selected dispatch stacks from the study. Figure 13 depicts the more unserved energy to meet projected demand on a peak demand day in BAU scenario and Figure 14 shows the peak demand met with RE capacity addition.

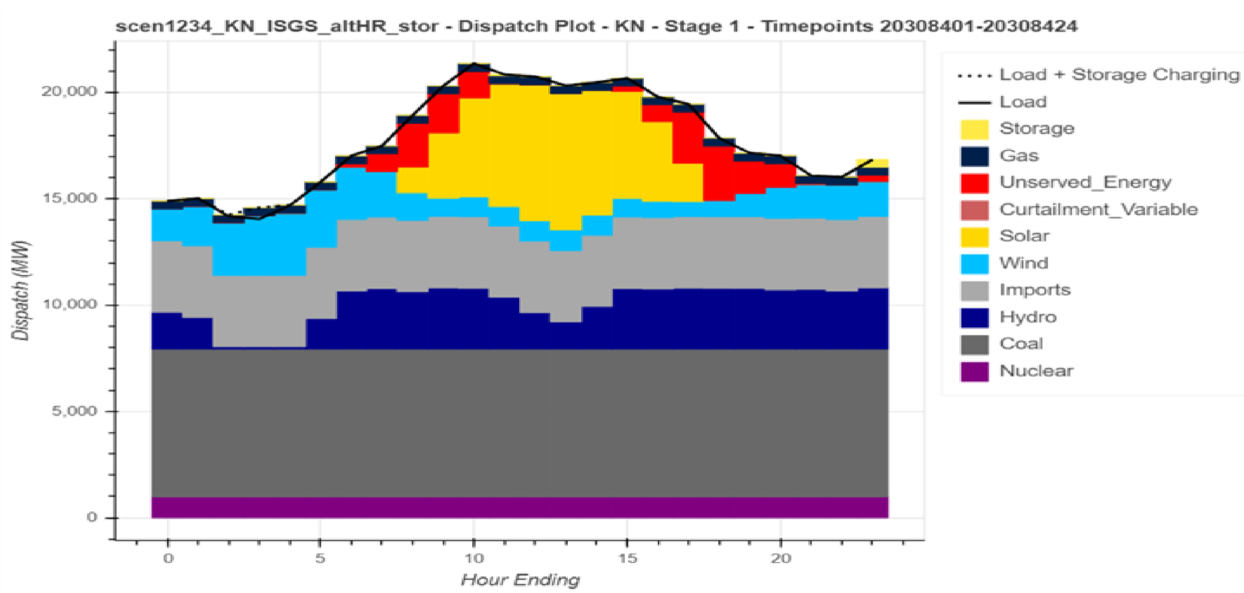



Figure 13: BAU_Peak demand day
Source: CSTEP analysis

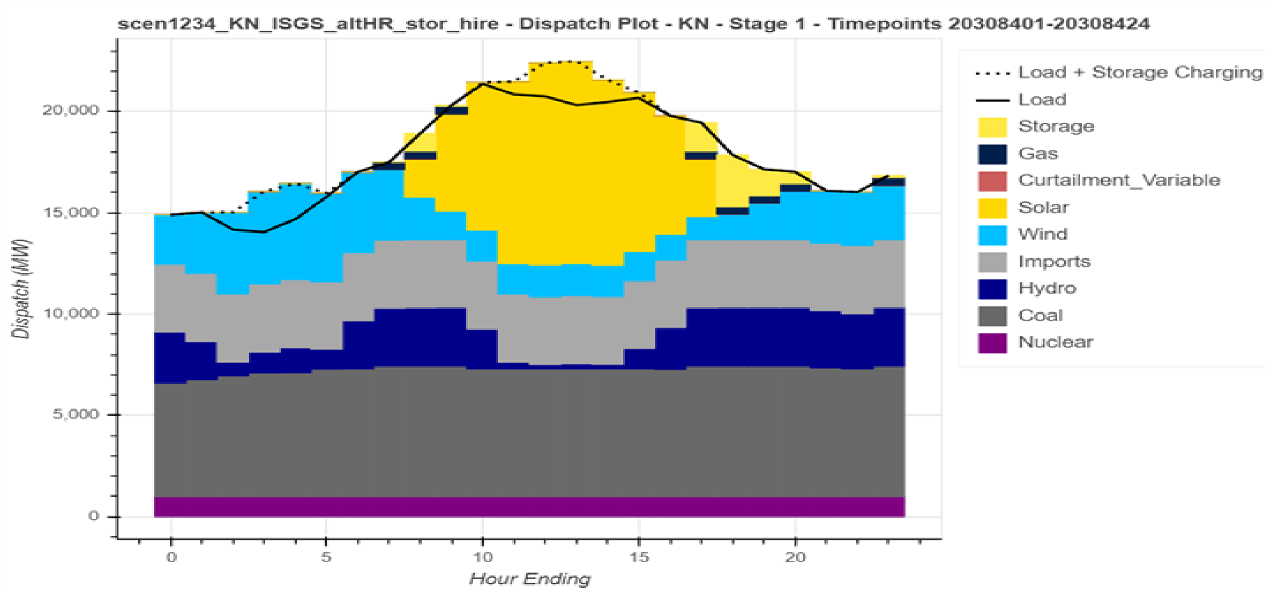



Figure 14: BAU_High RE Peak demand day
Source: CSTEP analysis

The following Figures 15 and 16, show that in the BAU_High RE scenario more variable energy curtailment is observed during peak of solar plus wind day, and also the more curtailment of variable energy during the peak monsoon month (July).

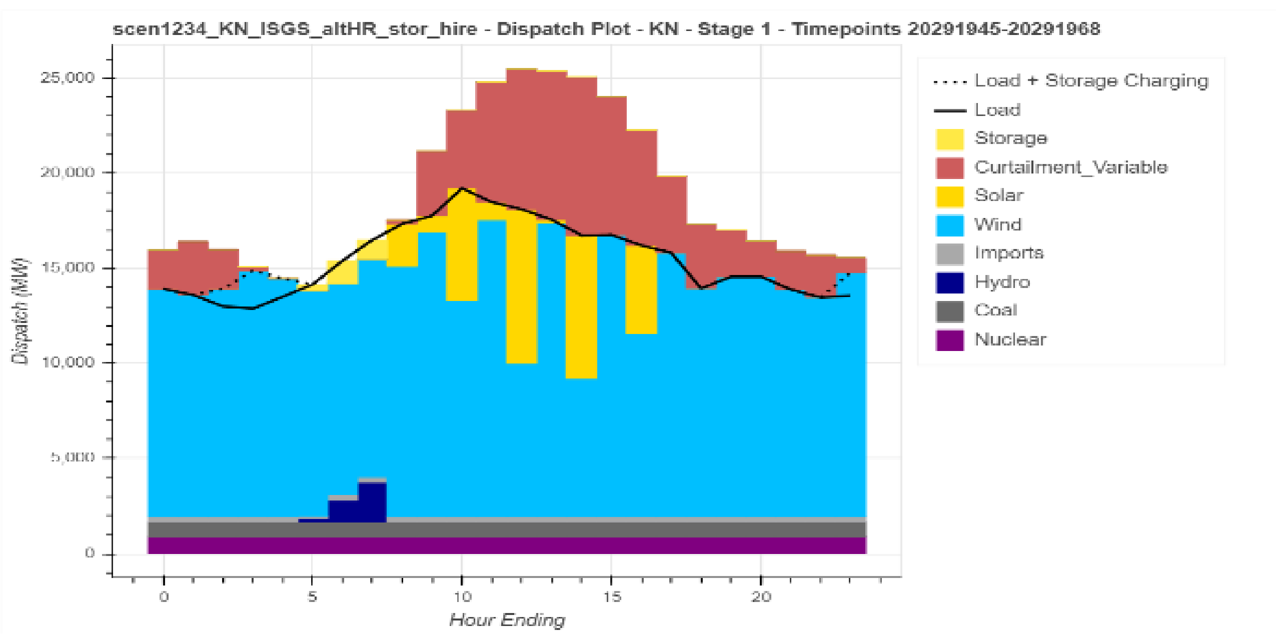



Figure 15: BAU_High RE Peak of Solar + Wind day Source: CSTEP analysis
Source: CSTEP analysis

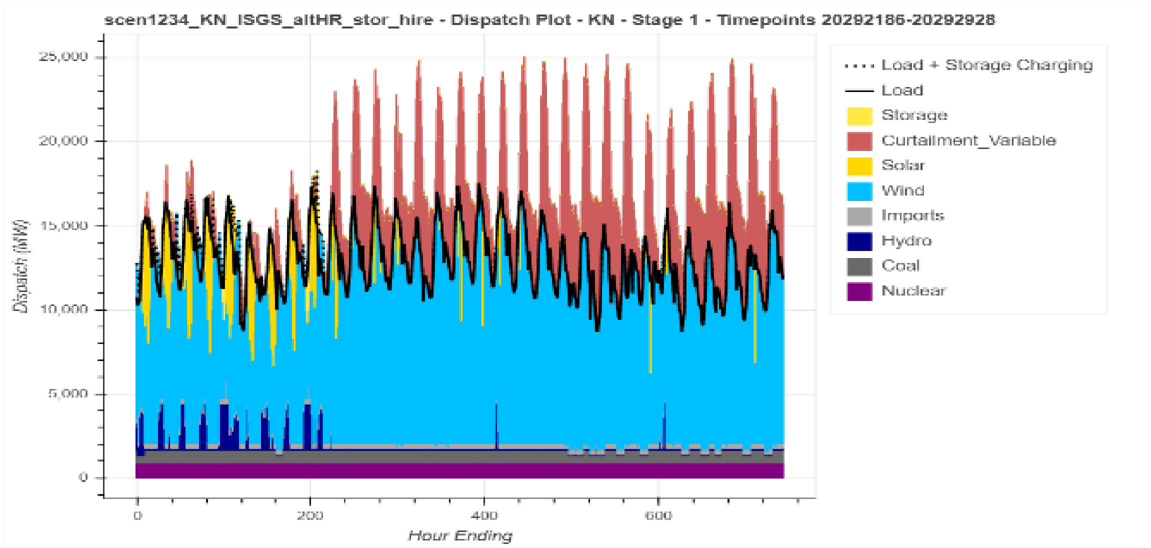



Figure 16: BAU_High RE July month
Source: CSTEP analysis

The RE share in the Karnataka state energy mix is around 33%, 48% and 39% in the BAU, High RE and High Solar scenarios respectively, as shown on Figure 17. Nuclear generation is constant across all the scenarios, the hydro share varies between 8% and 9%, and generation from gas is around 1%. The generation from coal plants is around 43% in the High Solar scenario and 35% in the High RE scenario.

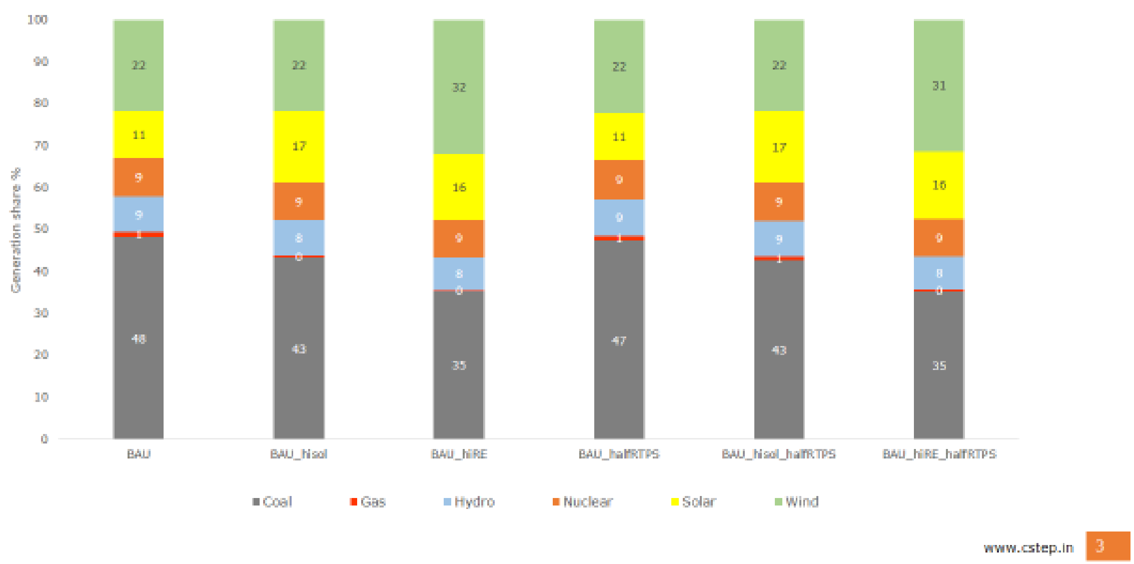



Figure 17. Karnataka Energy Mix under the 3 scenarios, 2030
Source: CSTEP analysis

As shown in Table 5, in the High RE scenario the share of RE increases to 48% of generation, while VRE curtailment increases to 9% with hydro curtailment also increasing to 5%.

In the High Solar scenario the share of RE generation increases to 39% with minimal curtailment (below 1%) of VRE and hydro.

| Scenarios/Particulars | Business As Usual (BAU) | BAU_Half RTPS | BAU_High RE | BAU_High RE_Half RTPS | BAU_High Solar | BAU_High Solar_ Half RTPS |
|---|---|---|---|---|---|---|
| VRE curtailment (MU) | 25 (0.06%) | 27 (0.07%) | 5,852 (9%) | 6,141 (9.4%) | 179 (0.37%) | 175 (0.36%) |
| Hydro curtailment (MU) | 0 | 0 | 516 (5.2%) | 498 (5.1%) | 0 | 0 |
| Unserved energy (MU) | 675 (0.6%) | 2,421 (1.93%) | 2 | 15 | 6 | 469 (0.38%) |
| RE energy share in total generation | 33% | 33% | 48% | 47% | 39% | 39% |

Table 5. Key findings for each scenario: generation, curtailment and unserved energy
Source: CSTEP analysis

Key outcomes of the analysis include:

- In the absence of high solar and wind (BAU), maximum unserved energy is observed, especially with the retirement of the RTPS Units 1-4 (210 MW each).
- In the High RE scenario, significant hydro curtailment along with RE curtailment is observed, due to low demand and more wind generation during monsoon season.
- The High Solar scenario is the most feasible option with an RE share of 39% in the energy mix.
- In the High Solar scenario, state's clean energy share would be 48% with Hydro.
- In the High Solar scenario, state demand can be easily met with minimum unserved energy (0.38%) even after retirement of RTPS Units 1-4 (of 210 MW each).
- Solar capacity addition to be preferred over wind, as Karnataka experiences peak demand during summer months.
- Instead of opting for curtailment, an inter-state power transfer can be more efficient for the High RE scenario.

## 4. Renewables integration solutions for Karnataka

There is an agreement across all stakeholders about the importance of active management and adjustment of the policy, market and regulatory framework to unlock the technical power system flexibility resources. In certain cases adjustments to the institutional framework may also be beneficial.

In this chapter we highlight hardware and infrastructure solutions, alongside policy recommendations and international insights for the future integration of solar and wind in Karnataka.

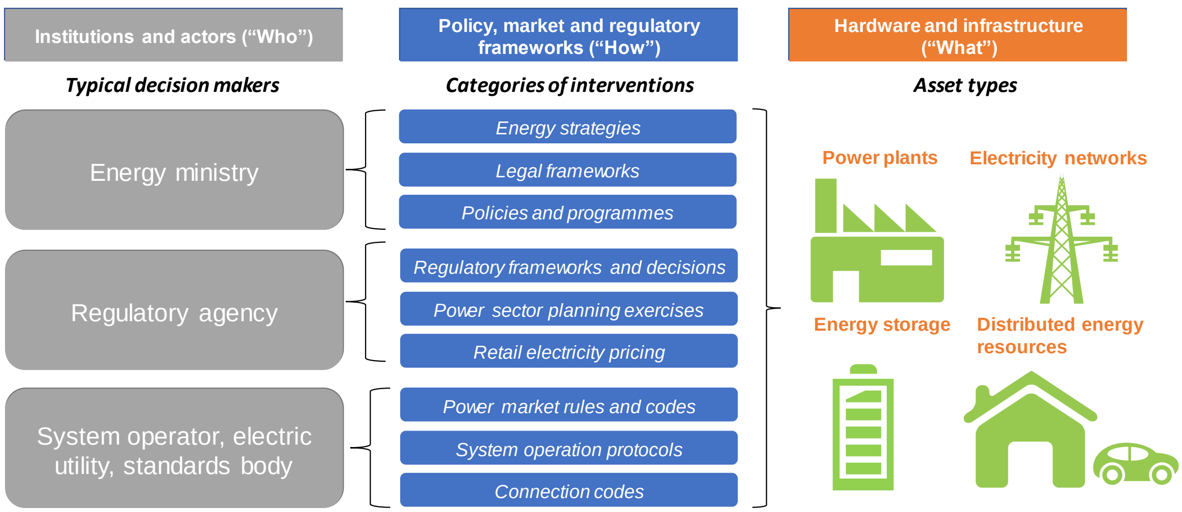



Figure 18. Power system flexibility embedded in the policy framework
Source: IEA analysis

### 4. 1 Increasing demand side flexibility

The following sections highlight some key opportunities for increasing demand response by 2030 by tapping into demand response from agriculture and buildings as power system flexibility solutions.

As users are becoming more and more proactive through digitalisation and smart devices there is significant opportunity for their active involvement in the power system flexibility by providing demand response services.

In the international context, demand side response (DSR) is often categorized into implicit and explicit demand response. With implicit demand response, consumers adjust their electricity consumption in response to dynamic price signals. By contrast, explicit demand response is offered through mechanisms such as balancing markets, capacity mechanisms or direct load control where a system operator can call on distributed energy resources (DER) to be dispatched. In order to unlock both implicit and explicit DSR the right intervention mechanisms needs to be in place that enable consumer demand and other DERs to serve as flexibility assets.

Karnataka has a unique morning peaking load curve, for example Figure 19 below shows the load curve of 17 March 2021, a typical Wednesday with a peak at 10 AM in the morning. The increasing share of demand side resources, namely rooftop solar is expected to reshape this demand curve in the coming years, with rooftop self-generation typically reducing demand in the midday hours, when some rooftop solar owners typically also feed into the local grids.

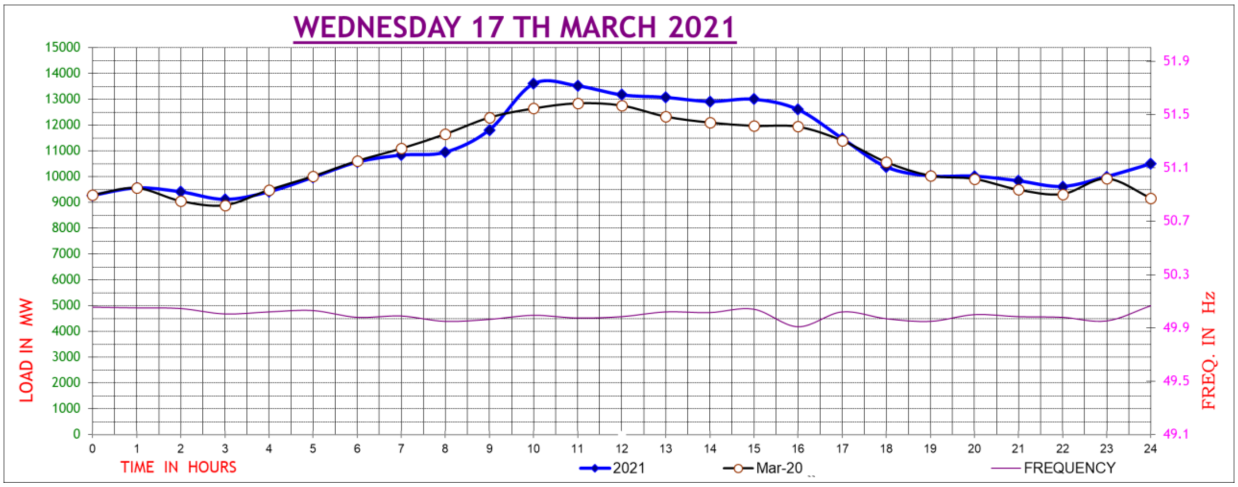



Figure 19. Karnataka Load curve and frequency, 17 March 2021
Source KPTCL SLDC

### 4. 1. 1 Agricultural demand response

Agricultural pumping constitutes up to 33% of total electricity consumption in Karnataka. Today agricultural demand response already plays an important role in balancing the power system of Karnataka. Agricultural demand response is a significant power system flexibility opportunity, because it can be the lowest cost way to align a significant amount of demand with solar peak hours.

Additionally tariff reforms can help move from the current practice of *agricultural demand shifting* (where agricultural users play a passive role) to *agricultural demand response* (where agricultural users respond to a price signal and benefit financially from providing flexibility). This is in line with international market reforms described in the following section, where the overarching long-term objectives are that all different flexible resources (both demand and supply side) compete on an equal footing.

### 4.1. 2 Rooftop solar regulatory innovation for the future system

Distributed energy resources, namely rooftop solar and solar pumps, act as proactive demand side resources that are capable of meeting electricity demand behind the meter while also feeding additional power into the local distribution network. However, state system operators and distribution companies are concerned about the rise of rooftop solar systems due to their impact on distribution system stability and demand forecast uncertainty.

The uptake of rooftop solar is approaching significant levels in India's states. By February 2021 Gujarat was the leader of rooftop solar deployment with nearly 1 GW of installed capacity, followed by Maharashtra, Karnataka and Rajasthan with over 200 MW rooftop solar installations while some additional states had over 100 MW installations including Delhi, Haryana, Uttar Pradesh and Punjab. Based on the Karnataka state level rooftop solar targets we expect significant increase in rooftop solar deployment by 2022.

According to BESCOM, there is currently a lack of real-time visibility and controllability of distributed solar resources for both distribution and transmission companies. At present, rooftop solar generation is not being monitored in real time, but the distribution company takes into account rooftop generation as part of the demand forecast submitted to SLDC, similarly to captive generation.

International insights from the global rooftop solar frontrunners can provide useful insights for Indian states. As shown on Figure 20, rooftop solar capacities in Belgium, Germany and Australia are forecasted to grow significantly, reaching over 20% of total capacity by 2024, well above the level in India at around 3%. International experiences from Germany, UK, Australia, California and Hawaii shows that the visibility of rooftop on the demand side can be improved through connection requirements embedded in DISCOM and transmission connection codes.

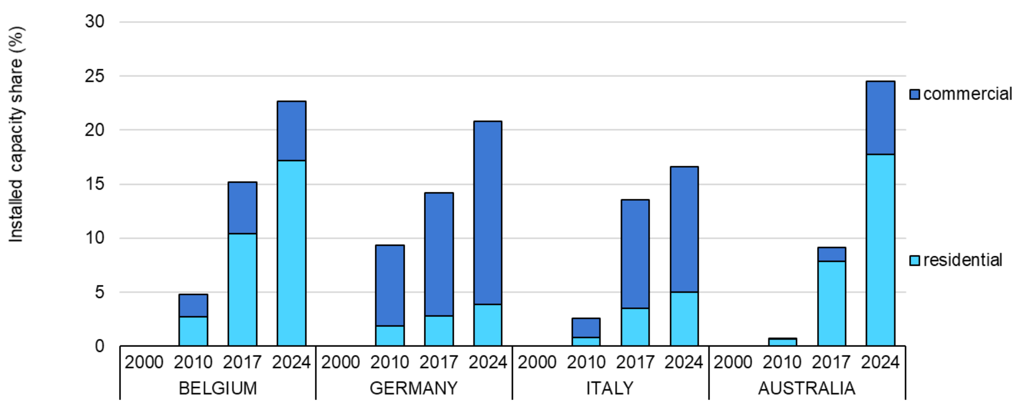



Figure 20. Rooftop solar capacities (residential and commercial) for developed countries from 2000 to 2017 and projected capacities for 2024
Source: IEA analysis

The German rooftop solar experience, with its over 1.8 million rooftop PV systems by 2020, shows that distributed PV can support the low-voltage network with voltage stability and reactive power. GIZ research shows that PV inverters available in the Indian market are capable of providing reactive power support, and that CEA connectivity regulation changes can unlock this potential going forward.

In Australia, with 2.75 million rooftop solar systems with a combined capacity of over 18.6 GW to date, tracking existing capacities and locations is managed through use of the DER registry portal as provided by the Australian Energy Market Operator (AEMO). This register does not provide real-time information, which requires smart metering or alternative forms of monitoring. Even in Victoria, where every household has a smart meter and 21% of all houses have rooftop solar, high resolution (e.g. hourly) data is not available dynamically to the distribution companies, but rather, smart meters submit half-hourly data every 24 hours. This data has been found to provide sufficient insight for the distribution companies for the forecast of rooftop solar in conjunction with the weather forecast, as rooftop solar output is fairly predictable depending on known weather patterns.

The key rooftop solar challenges observed in Australia include local network congestion at specific times and points in the network, high local voltage levels (over 102% of nominal voltage) and reverse flows to the distribution systems during the day when demand is low. Distribution networks have been experiencing more reverse flows since PV has become cheaper and houses are installing larger systems, with the average size of newly installed systems recently reaching 9 kW. One of the solutions is a software-based approach called dynamic operating envelopes, which is being piloted by distribution companies. This allows the export limit to the distribution system to be varied depending on how much can be accommodated at specific times. National rollout and the detailed rules and regulations are currently ongoing. In Australia, rooftop solar currently receives a fixed (non-dynamic) feed-in tariff in most cases. But in the future moving to 5-minute settlement on wholesale markets will also provide new opportunities.

Based on these international examples the Karnataka can consider few actions to improve visibility of rooftop solar in the state, as the first step. State regulators could appoint an entity to develop distributed solar registry platform for all state DISCOMs for solar pump and rooftop solar connections, included in (new and amended) connection requirements. The registry data would ideally be publicly available in an anonymous format and data should also be made available for SLDC by DISCOMs. In parallel, DISCOMs can require distributed solar registration from its consumers for future installations in the above-mentioned platform. DISCOMs can also develop a roadmap for distributed solar forecasting and assess technical requirements and potential policies to support more rooftop solar uptake, such as time-of-use tariffs (included in the following section). Positively, BESCOM has developed a simplified solar rooftop application registration platform, where consumer as well BESCOM officers can tract the application/ no. of applications, issue technical feasibility through online, work completion report by consumer up to commissioning of distributed solar plants, and it is recommended that other DISCOMs develop similar solutions.

### 4.1.4 Tariff reforms to increase demand side flexibility

In the future, electricity prices and tariff design can become one of the most important tools to enable more demand side flexibility in India. Electricity tariff design and tariff options may need revision with the increasing share of renewables, as the timing of the system use for different consumers will become critical, especially at times when solar generation is high. The tariff changes can shift significant user volume from low solar times to high solar times and thus save system level costs thus lead to better affordability.

Currently the time-of-day (TOD) tariff is implemented by Karnataka and is compulsory for the large industrial and commercial consumers and option for smaller industrial and commercial users. The BESCOM peak TOD hours are during the evening peak, from 18.00 Hrs to 22.00 Hrs. As rooftop solar will continue to reshape the demand curves, the adjustment of TOD timeslots can be useful.

Time-of-use (TOU) tariffs are the key policy requirement for tapping into flexibility from industry, buildings including cooling demand, water heating demand and other household electricity uses, as well as electric vehicle smart charging. Additionally, tariff reform can help move from the current practice of agricultural demand shifting, where agricultural users play a passive role, to pro-active agricultural demand response, where agricultural users respond to a price signal and benefit financially from providing flexibility. Similarly, demand response from cooling loads and EVs would critically depend on the price incentives given to consumers.

Some international examples of how tariff system can better align solar generation with peak demand is the TOU rates policy implemented in California, Denmark and the UK.

The California Public Utilities Commission (CPUC) TOU tariff is a rate plan in which rates vary according to the time of day, season, and day type (weekday, weekend or holiday). Higher rates are charged during the peak demand hours and lower rates during off-peak (low) demand hours. Rates are also typically higher in summer months than in winter months. This rate structure provides price signals to energy users to shift energy use from peak hours to off-peak hours. The chart in Figure 21 below shows the pricing for an illustrative time-of-use rate plan. Red indicates high price periods, yellow indicates moderate price periods, and green indicates low price periods.

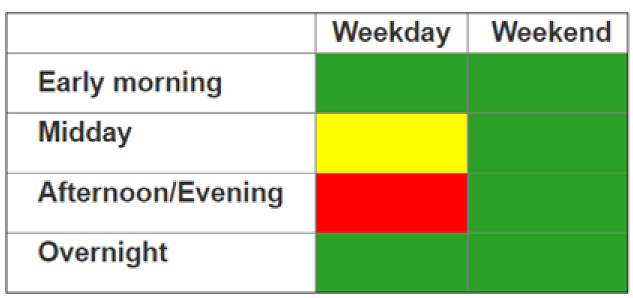



Figure 21. Illustration of the California time-of-use tariff design
Source: CPUC.

TOU pricing encourages the most efficient use of the system and can reduce the overall costs for both the utility and customers. Prices are predetermined for each time period. Prices do not adjust according to day-to-day changes on the wholesale electricity market.

By 2020, all commercial, industrial and agricultural customers in California were already required to be on a time-of-use plan. The TOU rate is also mandatory for any consumer with rooftop solar systems, including residential consumers. It has been available as a choice for more than 10 years for other residential users as well, but very few residential consumers have actually switched to use these rates. As required by the regulator, the state's three investor-owned utilities started to shift their 22.5 million residential consumers to default TOU rates in 2020, making the TOU rate the default rate for everyone as opposed to an opt-in option. This is important because residential electricity users are known to be sticky and passive users, and as such, most users remain on the default rates because they simply prefer to avoid the administrative process of switching to another rate. During the pilots, the Californian utilities demonstrated that for every 10% increase in price ratio of the TOU rates, peak demand decreased in a range of 6.5%-11%.

The exact rules regarding TOU tariffs and metering determine the value allocation across the rooftop solar owners, non-rooftop consumers and the utilities. For example since 2016 in California all rooftop solar customers of regulated utilities are required to be on TOU rates. In California TOU peak periods have shifted from 11 AM - 6 PM to 4 PM - 9 PM as the rooftop solar deployment and demand response reshaped the demand curve.

Many Indian DISCOMs are already in a weak financial positions and express concerns about the increasing loss of revenues and increased cost of rooftop solar. The example of California shows that mandating TOU rates for all rooftop solar players also helps mitigate some of the utility's revenue loss. As bill savings of a rooftop consumer will be equal to the revenue loss of utilities, TOU rates reallocate the costs and benefits between utilities and rooftop users. The time of use tariff will typically result in higher rates in the evenings in California between 4-9 PM (when solar generation lowers) thus higher compensation for utilities for providing energy during peak hours for rooftop solar consumers. At the same time the rooftop solar owners tend to overproduce in the middle of the day when the feed-in rate falls into the lower rate category. Requiring all rooftop solar customers to be on time-of-day tariffs can help mitigate the revenue loss of distribution companies while also balancing cost shift between rooftop solar customers and non-rooftop customers.

In other markets like the Danish market retail customers can, by the end of 2020, be settled according to their hourly consumption and the hourly price, such that the day-to-day and hour-to-hour changes in the wholesale electricity market is reflected in the end-user tariff. This requires increased detail in metering capabilities, however before hourly meters were installed customers with a consumption of over 100 000 kWh/year were required to be settled according to the hourly price. In this way, larger customers were exposed to the hourly variation in the wholesale electricity market.

The UK's journey towards TOU tariffs has been gradual underpinned by consumer awareness and engagement programmes. The success of static TOU tariffs in the UK encouraged roll out of modern TOU tariffs. This had been largely possible due to consumer acceptance of these programs and present a case for applicability in the Indian scenario as well.

In Karnataka tariff reforms can include expanding the TOD pricing to more customers including residential users, adjustment of peak tariff slots, and switching more users to default time-dependent tariffs.

The international examples were made possible by the widespread digitalisation and use of residential smart meters. Additionally smart meters need to be coupled with other digital tools such as displays, notification systems or systems providing automation to provide demand response.

Smart meter deployment in Karnataka is still limited. Going forward, the more widespread rollout of advanced metering coupled with the results of currently ongoing studies can create a foundation for the introduction of TOU tariffs for residential users.

## 4.2 Power plant flexibility

In Karnataka, power plant flexibility will be increasingly important with the increasing deployment of solar and wind. Power plant flexibility includes faster start-up times, faster ramp rates, lower minimum stable levels and shorter minimum up and down times of coal power plants, as well as the ability for warm and hot starts. Minimum stable levels are important for allowing power plants to keep operating while accommodating high variable renewables output in certain hours, particularly for solar in the middle of the day.

This additional operational flexibility will require investments for certain power plants and the redesign of compensation of these power plants with more focus on compensation for flexibility and less focus on current tariff solutions (fixed and variable compensation).

India has national-level coal power plant flexibility directions that apply to centrally operated power plants, while state-operated power plants have their own coal power plant flexibility objectives. Considering that most of the scheduling is under the State Load Dispatch Centres for balancing state level demand with supply, it is important to assess and set flexibility requirements at the state level on a plant by plant basis.

Karnataka can develop a state assessment to determine if coal power plant flexibility is a preferred (most cost-effective and least pollution) solution in Karnataka. Developing a state criteria to select key coal power plants best positioned for flexibility investments, and state regulatory mechanisms to encourage new investments for selected coal power plants and redesign compensation for flexible coal power plants is recommended. Furthermore, investments need to be weighed against investments in flexibility sources from other parts of the system (such as storage, demand response, grids).

In the longer term, state-level ancillary service regulations and markets, combined with improved spot market participation, could help to remunerating flexible plant operation on a competitive basis with other flexible resources such as demand side, storage and grid flexibility.

## 4.3 Transmission

In 2021 there are still significant barriers in India for a large increase of inter-state trade. One of these is the lack of transmission capacity available for inter-state trade with neighbouring states. The key concern of electricity stakeholders is that delivery of transmission infrastructure takes longer than the delivery of solar and wind projects and therefore there is risk of structural delay of new transmission infrastructure. Additionally, the low level of availability of transmission infrastructure crossing state boundaries is also of concern. Karnataka would also benefit from improving co-ordination of scheduling and dispatch with neighbouring states.

The Southern Region transmission study by CSTEP highlights the need for additional transmission infrastructure to be made available for inter-state trade, which will help accommodate renewables in the region by 2030 (with the assumption of no additional power system flexibility improvements, beyond transmission). As highlighted by the CSTEP Karnataka power sector model studies in the previously presented Chapter 3, in a high RE future Karnataka can see significant curtailment of hydro, solar and wind, unless significant flexibility is added to the system. Inter-state transmission is one form of this additional flexibility.

The results of this type of transmission studies should be assessed together with studies that assess alternative power system flexibility resources as well, such as demand side, storage and power plant flexibility options to determine the least-cost flexibility options for Karnataka.

Better transmission interconnectivity can also help with future declines in system strength and inertia in Karnataka.

## 4.4 Storage

Energy storage, such as batteries and pumped storage hydropower (PSH), can provide significant flexibility for integrating renewables, and is particularly relevant in India for allowing high solar output during the day to be stored for later use to meeting evening demand.

Karnataka has nearly 4 GW of hydro facilities that supported the integration of solar and wind in the power system to date. Going forward Karnataka is actively considering the retrofitting of their existing hydro plants to operate in PSH mode as a way to help integration of renewables in their systems. Currently the retrofit is foreseen for a 2000 MW hydro plant.

According to the CSTEP Karnataka power system model, both batteries and PSH will play an important role by 2030 to manage solar and wind variability and minimize curtailment. However, the hydro capacity available for flexibility in 2030 will be limited by monsoon flows.

For short duration power system flexibility needs, battery storage co-located with solar generation is a more cost-effective solution than a PSH retrofit, as shown on Figure 22. The US Flexible Resources Initiative analysis completed by the Lawrence Berkeley National Laboratory (LBNL) shows that for up to 8 to 10 hours per day of storage, battery storage co-located with solar generation is more cost effective than PSH (based on the retrofit of existing hydro plants) in

Indian states. This is partly because battery systems are energy-constrained systems (increasing the energy (MWh) of a battery is more expensive than increasing its capacity (MW)), while pumped hydro systems are capacity-constrained systems (increasing capacity (MW) is expensive while increasing energy (MWh) is cheap by increasing the depth of water in the dam). As such, PSH is normally built for a storage duration of over 8 hours. The LBNL analysis also showed that by 2030, four to six hours of energy storage is cost-effective for diurnal balancing. The study found that the LCOE of solar co-located battery storage was around INRs 3.5/kWh in 2025 when 30% of average daily solar PV output is stored in the battery.

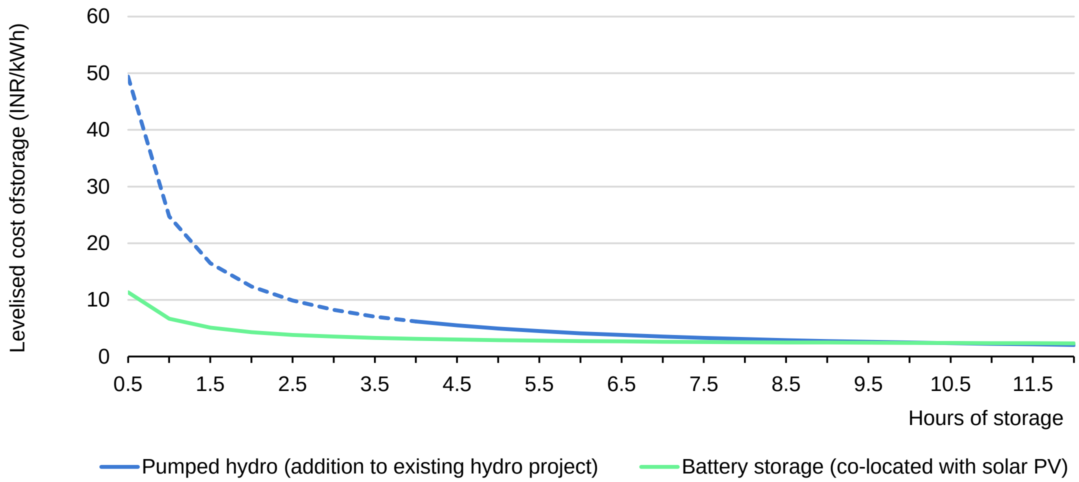



Figure 22. Levelised cost of storage – pumped hydro and battery storage in 2025

Source: Reproduced with permission from Abhyankar et al, 2021 (forthcoming).

Note: Very low storage durations for pumped storage hydropower given by the dotted line are illustrative only, as PSH projects typically have around 8 hours storage or higher.

In Karnataka, similarly to most Indian states there is currently no regulatory framework for battery storage. However, the Karnataka regulator is currently considering to create a market for battery storage. Analysis by the US National Renewable Energy Laboratory (NREL) of India's policy and regulatory readiness concludes that the key policy barriers include the lack of storage in energy policies and masterplans, and the lack of targeted support to early storage adopters. On the regulatory side, some current regulations explicitly restrict storage from providing services or earning revenue. This presents a barrier to maximising the cost-effective value of storage investments.

The development of a regulatory and remuneration framework for energy storage (with specific details added for batteries and PSH) is needed to capture its full value, including avoiding inefficient thermal investments, energy arbitrage opportunities for shifting the energy demand within a day or week, and ancillary services for managing the system ramps.

The strategy of the UK regulator, Office of Gas and Electricity Regulator (Ofgem), for a modernised, smart and flexible power system includes significant clarity, transparency and guidance for the role of storage after its initial exclusion from the UK Government's Smart

Systems and Flexibility Plan published in 2017. India, too, needs to define energy storage in a well thought out policy framework (for example, the Electricity Act) in order to expand deployment of storage systems in the country. The definition should acknowledge its flexible nature and applications, and its categorisation should be either generation, transmission and/or distribution assets, as has been done in the UK. As a result of ongoing market opportunities for batteries, the UK with over 800 MW, is the market leader for battery storage deployment in Europe, followed by Germany with over 500 MW. Battery investors in the UK actively participate in day- ahead markets, intraday markets and imbalance markets. Additionally, they access revenues from ancillary services markets and capacity markets, and from time of use rates when storage is placed behind the meter. Revenue gains are also made by avoiding network charges. The conclusion and recommendation for Karnataka is to start with a battery policy that can provide a long-term (over 4 years) revenue stream for the first battery investors and then move towards providing revenues from shorter- term services/products in the markets.

## 4.5 International examples of regulatory and market innovation

In Karnataka, being in Phase 3 means that there is an increasing role emerging for flexibility from PSH, grid-scale battery storage, smart charging of EVs and synthetic inertia. International experience highlighted in this sub-chapter shows that specific market and regulatory innovations are required to access the flexibility from many new and innovative power sector assets and solutions such as solar, wind, demand response, storage and batteries.

To reach equal access to compensation for flexibility for these new players, authorities need to review, and possibly reform, the current state regulation and market rules. Identification of barriers to competition for these new technologies can be the first step for the KERC in Karnataka. More specifically, storage (including batteries) faces barriers to enter and compete in the current regulatory setup, for example the eligibility of battery investors for fixed cost payments as thermal assets is still a question. At the same time, the development of new ancillary services and ancillary services market provides an opportunity to consider all the new technologies from the start.

Additionally, Karnataka grid codes can be reviewed and updated for system friendly connection and flexibility requirements for new solar and wind projects, including distributed solar (rooftop and pumps).

Comprehensively reviewing and removing market barriers for new technologies is an important ongoing task worldwide. Figure 23 shows what countries are addressing what type of technologies and related policies in different Phases of System Integration.

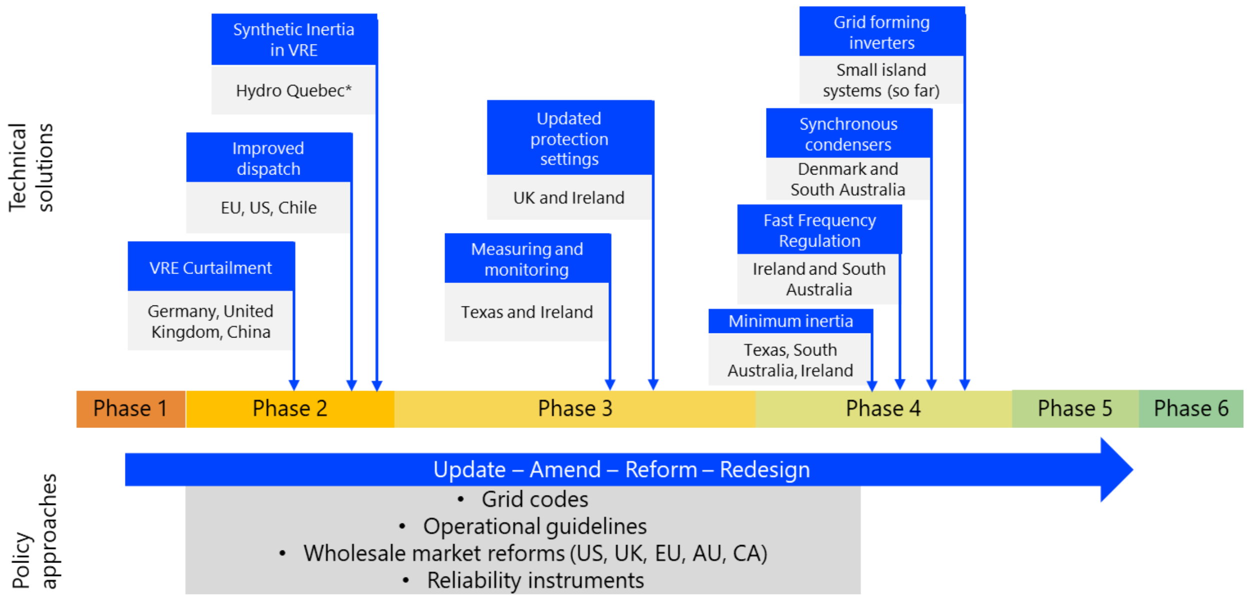



Figure 23. International insights into VRE integration solutions
Source: IEA analysis

For example, the U.S. Federal Energy Regulatory Commission (FERC), which regulates the wholesale electricity markets and the high-voltage transmission system, has issued a landmark ruling to review its market rules and remove unnecessary barriers to energy storage participation. This ruling opens the doors for all types of energy storage resources sited anywhere on the power system to participate in FERC's organized energy, capacity and ancillary services markets. Ideally, these markets would drive technological innovation, but current electricity market rules are largely tailored to legacy power plants, which can inhibit progress. Historically, market rules have been tailored to the operating parameters of traditional power plants like large hydropower and gas peaker plants, not smaller storage technologies. For example, some grid operators in the USA imposed minimum size requirements of up to 1 MW, which excluded smaller batteries.

FERC's rule also invites storage resources located on the distribution system (potentially behind-the-meter) to participate in the wholesale electricity markets. Again, therein lies the main controversy. While FERC can open the gates to its wholesale electricity markets and the high-voltage transmission system, states and other local authorities regulate the distribution system (a dichotomy formalized in the 1935 U.S. Federal Power Act). States and other local entities have therefore challenged the FERC rule.

The tension between federal and state authority is a common theme with newer, smaller resources like demand response, storage, and DERs that could provide services to both the transmission and distribution systems. Similar issues arise in other two-tiered jurisdictions like Australia, Canada, the European Union and of course India (IEA Commentary, 2019).

## 5. Solar and Wind Integration Roadmap for Karnataka

The following roadmap in Table 6 summarises the key policy recommendations for system integration of renewables highlighted in the report connecting them with a timeline, the system integration phases and key stakeholders.

| | Karnataka Solar and Wind Integration Roadmap | Phase 3 | Phase 4 | |
|---|---|---|---|---|
| | Technical and policy solutions | By 2022 | By 2030 | Most relevant stakeholders |
| Operations | Introduce more transparency and public availability of curtailment data (annual, monthly solar and wind curtailment (%) in the state) and consider publishing more specific reasons for curtailment decisions made by state load dispatch centre. | | | KERC<br>SLDC |
| Operations | Continue with existing agricultural demand scheduling in the short term. Towards 2030 transition from current demand shift practice to demand response with financial compensation for pro-active farmer flexibility. | | | SLDC, DISCOMs, KERC |
| Grid codes and planning | Design and implement technical flexibility requirements for new solar and wind investments. | | | KERC, KPTCL, SLDC |
| Grid codes and planning | Develop state assessment to determine if coal power plant flexibility is a preferred (most cost-effective and least pollution) solutions in Karnataka. Develop state criteria to select key state coal power plants best positioned for flexibility investments. Develop state regulatory mechanisms to encourage new investments for selected coal power plants and redesign compensation for flexible coal power plants. Further, investments need to be weighed against investments in flexibility sources from other parts of the system (storage, demand response, grids). | | | KERC, SLDC |
| Grid codes and planning | Review transmission investment needs for 2030 targets and compare the cost of these investment with other flexibility resources. | | | KPTCL |

| | | | | |
|---|---|---|---|---|
| | KERC or KREDL to appoint an entity to develop distributed solar registry platform for all DISCOMs for rooftop solar connections, included in connection requirements. The registry data would ideally be publicly available in an anonymous format and data should also be made available for SLDC by DISCOMs. | | | KERC, DISCOMs SLDC, KREDL |
| | Following BESCOM developments, DISCOMs to require distributed solar registration from its consumers for future installations in the above mentioned platform. DISCOMs to develop a roadmap for distributed solar forecasting and assess technical requirements and potential policies to support this. | | | DISCOMs, KERC, KREDL |
| Power market and regulation | Develop view and policy on solar and wind curtailment (must run status) and a compensation framework for future curtailment. | | | KERC, KPTCL, SLDC |
| | Consider introduction of new ancillary services and design of ancillary services market | | | KERC, SLDC, |
| | Review regulatory and market environment to identify barriers to entry for new storage technologies: such as pumped hydro, batteries and demand response. Review the balance of compensation for these resources for energy, capacity and ancillary services. | | | KERC, SLDC, private sector |
| | To introduce battery storage in the state it is advisable to start with a policy that can provide long term (over 4 years) revenue stream for the first battery investors and then move towards providing shorter term services/products in the markets. | | | KERC, SLDC |
| | Review existing power trading (banking) with other states and consider how to expand trading activity to provide regional balancing of solar and wind resources. | | | KERC, SLDC |
| | Making load curve data per DISCOM and per consumer type for each state transparent and | | | KREDL |

| | | | | |
|---|---|---|---|---|
| | public would help private and public sector players calculate the return on investment in demand-response programmes and assess their optimal tariff choices. | | | KERC<br><br>DISCOMs |
| | Consider expansion of TOD tariffs to residential and agricultural users, review and develop policies for roll out of minimum technical requirements, including smart meters. Consider requiring all rooftop consumers to be on TOD tariffs. Regularly revisit TOD timeslots as rooftop solar will shift demand curves. | | | KERC, DISCOMs |
| Retail | Progressively move different consumer types to default TOD rates. | | | DISCOMs, KERC |

Table 6. Solar and Wind Integration Roadmap for Karnataka
Source IEA Analysis, 2021

## Acknowledgements & Preparation of the workshop and report

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## Annex 1. Workshop presenters

| Name (FAMILY, first name) | Organisation (A to Z) |
| --- | --- |
| EBOHON Samuel | Arup |
| KUIPER Gabrielle | Australia, former Energy Security Board |
| SHEELA G | BESCOM |
| PILMORE-BEDFORD Jeremy | British High Commission |
| SINGH Anoop | Centre for Energy Regulation IIT Kanpur |
| KV Harikrishna | CSTEP |
| RAVINDRANATH Milind | CSTEP |
| MOHAN Kapil (NOHAN Kapil) | Government of Karnataka |
| DOCZI Szilvia | IEA |
| HERNANDEZ Alejandro | IEA |
| MEDIRATTA Rajesh | India Energy Exchange |
| MANJULA N. | Karnataka Power Transmission Corporation |
| ABHYANKAR Nikit | Lawrence Berkeley National Lab |
| KUMAR DEWANGAN Vivek | Ministry of Power |
| MISHRA Arun Kumar | Ministry of Power |
| BURMAN Diane | New York State Utilities Commission |
| RAM Rajnath | NITI Aayog |

# Annex 2. References


Karnataka Workshop agenda, presentations and recording
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## Annex 3. Abbreviations, acronyms and units of measure

| | |
|---|---|
| **CEA** | Central Electricity Authority |
| **CEM** | Clean Energy Ministerial |
| **CER** | Center For Energy Regulation |
| **CERC** | Central Electricity Regulatory Commission |
| **CTU** | Central Transmission Utility |
| **DISCOM** | Distribution Company (In India) |
| **ESS** | Energy Storage Systems |
| **GENCO** | Generating Company |
| **GIZ** | Deutsche Gesellschaft Für Internationale Zusammenarbeit |
| **IEA** | International Energy Agency |
| **IESA** | India Energy Storage Association |
| **IIT** | Indian Institute of Technology |
| **ISGS** | Inter-State Generating Station |
| **LCOE**<br>**LCOS** | Levelised Cost Of Electricity<br>Levelised Cost Of Storage |
| **MNRE** | Ministry of New and Renewable Energy |
| **NITI Aayog** | National Institution for Transforming India |
| **OECD** | Organisation for Economic Co-Operation and Development |
| **PGCIL** | Power Grid Corporation India, Ltd. |
| **POSOCO** | Power System Operation Corporation, Ltd. |
| **PPA** | Power Purchase Agreement |
| **PSH** | Pumped-Storage Hydro Electricity |
| **PV** | Photovoltaic |
| **RAP** | Regulatory Assistance Project |
| **RE** | Renewable Energy |
| **REMC** | Renewable Energy Management Centre |
| **RPO** | Renewable Purchase Obligation |
| **SLDC** | State Load Dispatch Centre |
| **STU** | State Transmission Utility |

| | |
|---|---|
| **TERI** | The Energy Resource Institute |
| **VRE** | Variable Renewable Energy |
| **WRLDC** | Western Region Load Dispatch Centre |
| **21CPP** | 21st Century Power Partnership |