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

Volume 2.

Gujarat Power System Transformation Workshop Report

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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 a wide range of stakeholders including system 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. In 2018 the IEA 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 partnership with NITI Aayog, has been organizing a series of state-level Power System Transformation Workshops. The objective of the workshops is to help inform the state governments' actions for system integration of solar PV and wind. In 2020 two workshops were held focusing on Maharashtra (February) and Gujarat (October). The third workshop focused on Karnataka on 19 January 2021.

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**	**Feb-March 2021 (TBC)**
Tamil Nadu (TBC)	*TBC*	*virtual*	*TBC*
Rajasthan (TBC)	*TBC*	*TBC*	*TBC*

Table 1: IEA India Renewables Integration work: timeline

Following the completion of all three workshops, an India Power System Transformation report will be drafted and published on the IEA and NITI Aayog websites in early 2021. Some of the analysis is also featured in the IEA World Energy Outlook Special report on India, which was 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 most 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 (19%) and Gujarat (16%) (Figure 2). These states are experiencing system integration challenges ahead of most countries internationally, and with ambitious targets are set for further challenges in the future. 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 years 2020 and 2021.

Instead of focusing on RE in the broad sense of the word, the following IEA analysis and this report focusses on wind and solar, referred to as variable renewable energy (VRE) because the variability in the system is one of the key drivers of renewables integration challenges. The report also takes into account the impact of other renewables, namely hydro and bio-energy, noting that these normally impact system integration of renewables positively, as they often are dispatchable 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. 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).

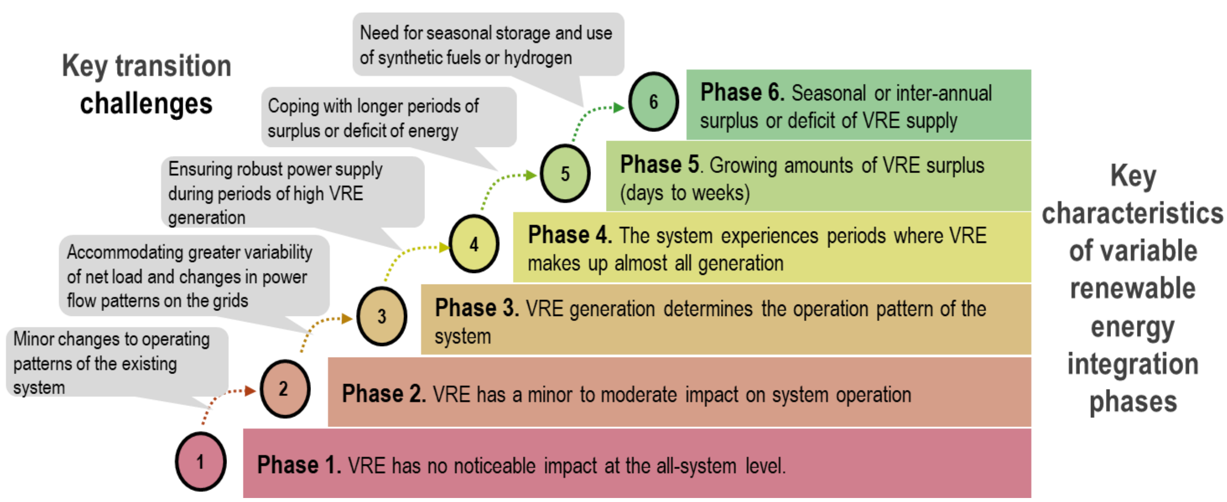

Figure 1: Phases of System Integration of Renewables, Source IEA

As seen in chart below some countries internationally, and few Indian States like Gujarat, Karnataka and Tamil Nadu are already in phase 3 and fast approaching phase 4; and are already facing challenges to integrate the high shares of variable renewables. The workshop highlighted learning for the state of Gujarat from the international experiences of integrating high shares of VRE, particularly from the UK, Ireland, US States of Texas and California, and South Australia. These lessons can help Gujarat to leapfrog some of the integration challenges and assist system transformation process in the state.

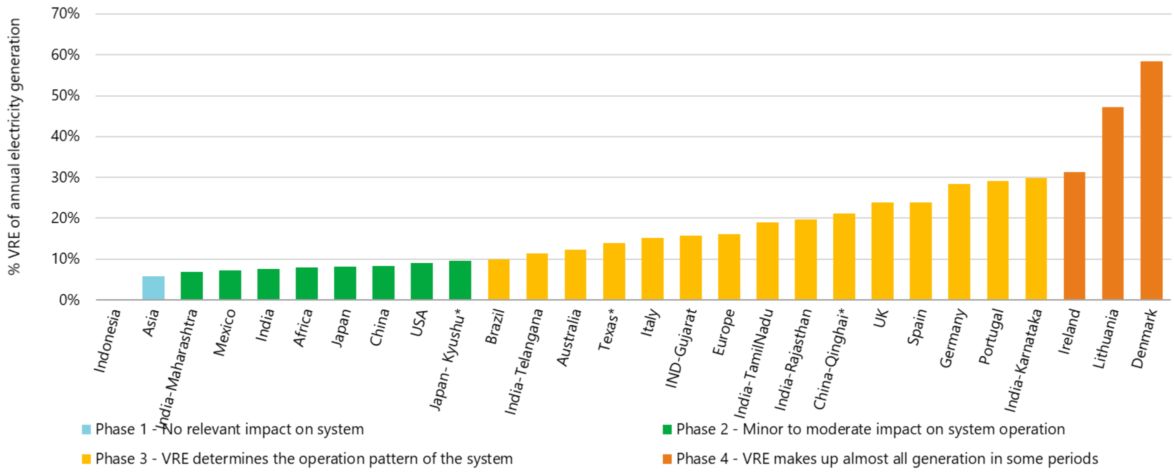

*Figure 2: Countries and Regions in Phases of Renewables Integration, Source IEA analysis, 2019 data (*indicates 2018 values)*

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, while ensuring system security. 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 (ramping, startup, demand response etc) highlighted in the table below. According to the IEA phase assessment framework, different flexibility resource types acting at different time scales will be more pronounced 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 Several VRE rich states by 2025	Phase 3 Gujarat, Karnataka, Tamil Nadu in 2020	Phase 2 India as a whole, Maharashtra in 2020	Phase 4	Phase 5 Phase 6

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

In Gujarat, currently in Phase 3, the system operation flexibility need is greatest for the resources that provide flexibility within *minutes to hours,* thus helping to overcome very short-term variability of solar and wind. Greater penetration of solar energy would place greater demand for flexibility with even faster response time. Later in Phase 4, more focus on ultra-short term flexibility capabilities will be required in order to provide flexibility within seconds, and additional focus on flexibility within the days of the week. Then in Phase 5 and 6, more 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 identified timeframes across the Phases of RE integration are included in detail in the table below. These power system flexibility enablers can be generation, grid, storage assets, demand-side management and sector coupling. The following chapters of the report address the flexibility enablers that are most relevant for the state of Gujarat, given their current level of VRE deployment.

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 Gujarat state overview

Gujarat traditionally has a coal dominated power system, and is now witnessing rapid increase in the share of renewables. As of November 2020, the total installed electricity generation capacity of 36 GW includes 16 GW coal, 6.6 GW gas, 0.8 GW of large hydro and, the rest of about 11.8 GW comprises of renewable energy sources including solar, wind and small hydro.

The increase of renewables is mainly driven by ambitious state-level targets, specified in capacity terms for 2022 and 2030 (Table 1.). The targeted capacity mix by 2030 would make Gujarat a solar dominated power system, with the majority of utility scale solar. This is a significant transformation from the current coal dominated power system.

Renewables in Gujarat	**2020** *(as on 30/11/2020) (MW)*	**2021-2022** *targets (MW)*	**2029-2030** *targets (MW)*
Solar *(excluding rooftop)*	2772	5661	26660
Rooftop solar	866	2132	6132
Onshore wind	8042	7695	11446
Offshore wind	0	0	1000
Other renewables *(excluding large hydro)*	144	211	304
Kutch hybrid park *for export to other states*	0	0	20000

Table 2. Gujarat solar and wind historical data and targets, Source: CEA, MNRE, *GUVNL*

The increasing annual share of solar and wind energy generation in Gujarat, up from today's 13%, will redefine how the state's power system should be organized, planned and operated in future. System integration challenges are pronounced when we look at the daily snapshot of power generation (Figure 4). While solar and wind can meet over 32% of the daily generation today (maximum recorded was on 15th July 2019 during 2019-20), this number is expected to increase to 55% by 2022 and to almost 90% by 2030. This means that, by 2030, Gujarat's power system is expected to experience challenges that have not been experienced by any Indian state today.

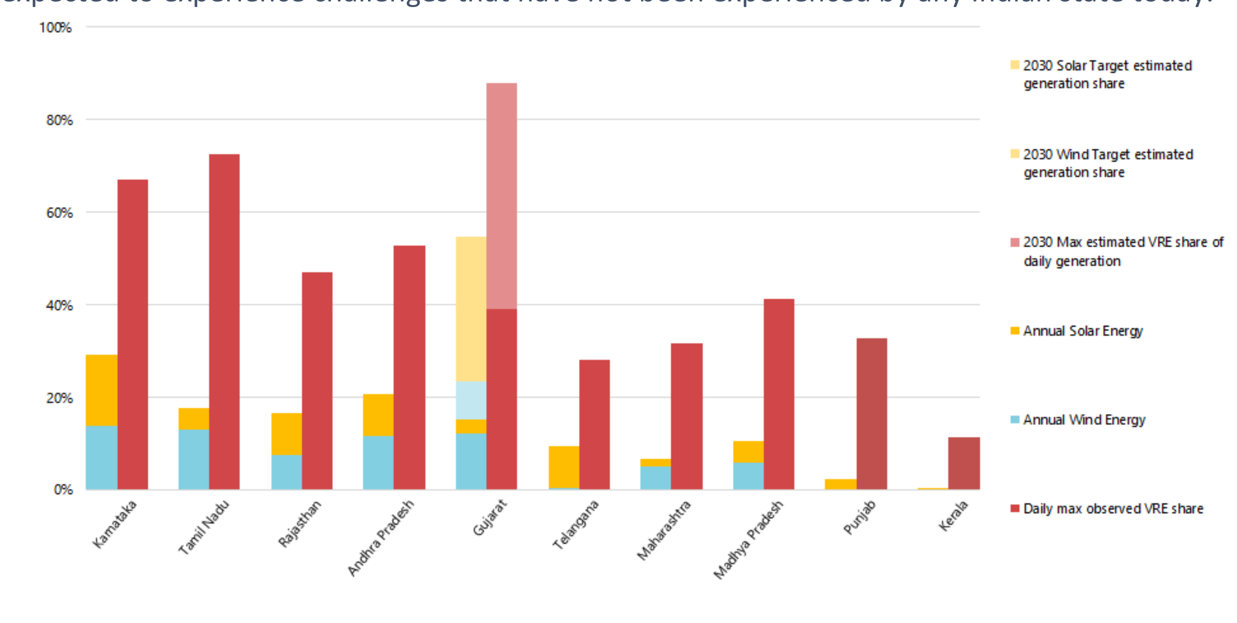

Figure 5. Yearly average and daily maximum solar and wind share in generation in RE rich States of India, Source: IEA analysis, 2020,

Note: Gujarat target values include Kutch hybrid park capacity for export to other states which is not included in the power system model
Source of data:
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 Workshop

2.1 The key RE integration challenges and solutions in Gujarat

The Gujarat workshop was held on 7th October 2020 in partnership with the Gujarat Government, NITI Aayog and the Centre for Energy Regulation, IIT Kanpur. The Gujarat workshop was a closed-door virtual event where more than 65 key local stakeholders and more than 10 international stakeholders shared ideas and identified renewable energy 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 Gujarat, while identifying and prioritizing deploying flexibility options that could ensure cost effective system planning and operation. The workshop was organised in three sessions, which included:

1. Opening and high-level context session
2. Gujarat's Power System in light of high shares of Solar and Wind
3. System flexibility roadmap for an evolving energy mix

Prior to the workshop the IEA has undertaken analysis and consultation with local stakeholders. Based on these consultations, the agenda was developed that focused on the most important RE integration questions with relevance to Gujarat State. In line with the identified important topics, presentations were made by GERC, GUVNL, GETCO, Gujarat SLDC, GSECL (Genco), PGVCL (DISCOM), NITI Aayog, GERMI, Center for Energy Regulation, ARUP, Ampacimon, World Bank, India Smart Grid Forum and GIZ. All presentations are available for download at the IEA workshop webpage (here). The full list of presenters and workshop participants is provided in the Annex 1.

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 pointed to regulators as the key institutions for transition towards more renewables, followed by policymakers, the private sector, DISCOMs, the system operator – SLDC and GETCO.

Secondly it was found that significant challenges exists for reaching the Gujarat 2030 renewables targets. The most important challenges as seen by Gujarat stakeholders listed in the order of priority are the forecast of solar and wind, transmission challenges, technical challenges such as inertia, system strength, frequency and voltage issues, demand forecast, future curtailment of solar and wind and distributed energy resources. The workshop presentations therefore covered these topics (Table 3) alongside further in-depth analysis presented in this report.

Key Gujarat RE integration <u>challenges</u> identified *From highest priority to lower priority*	**Covered in workshop by key organisations**
Forecast of solar and wind	Yes, GERC, SLDC presentation
Transmission challenges	Yes, GETCO, Ampacimon and IEA presentations
Inertia, system strength	Yes, GETCO, SLDC and IEA presentation
Frequency and voltage issues	Yes, GETCO, SLDC and IEA presentation
Forecast of demand	Yes, GERC, SLDC presentation
Curtailment of solar and wind	Yes, GETCO, SLDC and IEA presentation
Distributed energy resources: rooftop solar, EVs...	Yes, GIZ presentation
Increasing consumer prices	Yes, GERMI presentation
Blackouts, outages	Yes, IEA

Table 3. Gujarat solar and wind integration challenges, Source: IEA analysis

Thirdly the workshop and the in-depth IEA analysis (Chapter 3 and 4) 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 Gujarat. The most important solutions in the order of priority are demand response (more specifically agricultural demand response), regulatory reforms, flexible coal power plants, tariff reforms and energy storage. The workshop presentations therefore covered these topics ((Table 3)) alongside further in-depth analysis covered in Chapter 3 and Chapter 4 of this report.

Key Gujarat RE integration <u>solutions</u> identified *From highest priority to lower priority*	**Covered in workshop by key organisations**
Demand Response	Yes, PGVCL and IEA presentations
Regulatory reforms	Yes, GERC, GETCO and IEA presentations
Flexible coal plants	Yes, GSECL and IEA presentation
Tariff reforms	Yes, GERC and ISGF presentations
Energy storage incl. batteries	Yes, SLDC, IEA and World Bank presentations
New ancillary services	Yes, SLDC presentations
Flexible solar and wind	Yes, IEA presentation
Flexible gas plants	Yes, IEA presentation

Transmission investment	Yes, GETCO and Ampacimon presentations
New technologies: hydrogen, EVs...	Yes, IEA presentation, sector coupling
Hydro plants	Yes, GSECL and IEA presentations

Table 4. Gujarat 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.

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

Gujarat contributes 12% to the national level renewables basket and is one of the front runners of the "climate efficient initiative". The state regulator GERC expects Gujarat to meet its targets of RE capacity of 17% by 2021. In the longer-term Gujarat state targets 65 GW for solar and wind combined by 2030, which includes 20 GW of capacity in a hybrid solar and wind park designed for exports to other states. Gujarat is one of the few states in India with financially stable DISCOMs with timely payments and excellent land availability driven by stable long term policy directions: (1) Land Allocation Policy for Wind, Solar and Hybrid Parks 2019, (2) Policy for Development of Small Scale Distributed Solar Projects 2019, and (3) Policy for allocating land, for development of Solar Projects in the vicinity of existing GETCO substations.(For more details refer to GUVNL presentation on the workshop webpage).

Forecasting of solar and wind

Forecasting of solar and wind was seen one of the most significant challenges by workshop participants. SLDC anticipates that 5000MW demand variation and 3500MW wind variation in a day will be common by 2030. To meet this variation and minimize start/stop of thermal plants, 4000MW of reserves can be required.

SLDC noted that additional flexibility will have to come from both the physical system and the institutional framework, such as market dispatch decisions closer to real time and better use of forecasting. The ongoing development of the Renewable Energy Management Center (Figure 6) will enable real time review and more accurate forecasting of solar and wind.

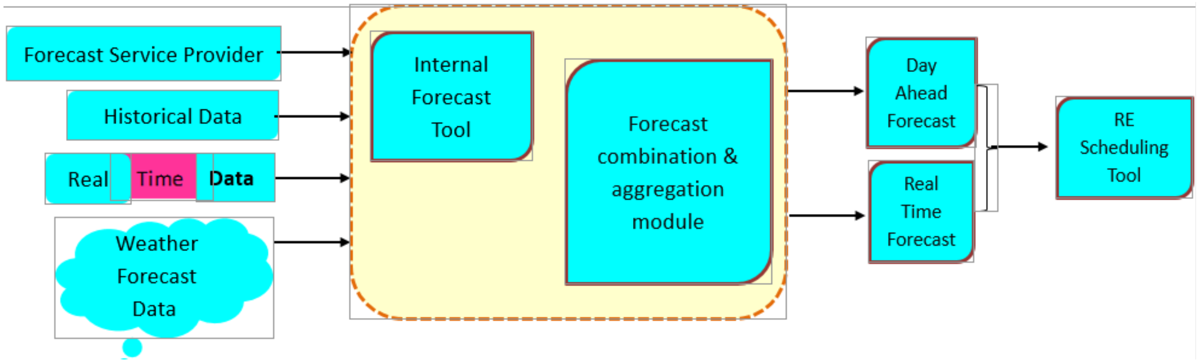

Figure 6. Renewable Energy Management Centre: Advance Forecasting Mechanism Support to System Operation being developed in Gujarat

Curtailment of solar and wind

Today the solar and wind curtailment in Gujarat is zero. However, in the future GETCO expects increasing system balancing costs associated with keeping the curtailment low, thus zero curtailment may not be the economically optimal choice in the longer run. In fact in other high shares of VRE systems some form of curtailment is deemed acceptable.

Arup presented RE integration challenges from the perspective of RE investors in India and Gujarat. It highlighted that increasing uncertainty of future energy losses (due to curtailment, outages, and electrical factors) is factored into the developer's Energy Yield Assessment, and is an important consideration for financing rates that also impact PPA offers. Arup highlighted that stable long term policy environment on curtailment and today's "must-run status" and improvement of solar and wind site data would have positive impact on future project design and thus investor confidence.

Transmission challenges and solutions

The GETCO (transmission utility in Gujarat, responsible for planning and operations) highlighted that currently Gujarat only faces some localized system integration challenges on the power system. The GETCO transmission expansion plan is designed to facilitate the planned RE deployment.

Ampacimon presented an innovative smart technology named Dynamic Line Rating (DLR) system for OHL; directly measuring critical parameters in RT at the conductor like, Sag, Wind speed & Line load. Computational engine delivers, available Line capacity (reserves) in RT; forecasts in Short term (30Mts.-4Hrs), Day ahead & D2 Forecasts. Capable of integrating with EMS/SCADA; hence Load – Generation balancing can be on actual capacity. Capacity gains around 30-50% experienced by TSOs in Europe, maximizing the use of transmission infrastructure. Similar benefits are envisaged for India / Gujarat; based on Ampacimon's study of conditions prevalent in India.

DLR can deliver quick relief from congestion woes without any compromise to safety, enabling optimized usage of existing infrastructure, managing grid with confidence during contingencies (with RT visibility), support faster deployment of DERs/wind-solar hybrid projects. DLR can also offer good impetus to offshore wind projects in Gujarat due to its relevance in grid planning, optimization of evacuation infrastructure, integrating wind farm output and bringing in economic benefits for deferring the investments costs of additional line infrastructure.

Inertia, system strength, frequency and voltage challenges and solutions

As Gujarat will move from synchronous generation to inverter based generation a number of system operation tools will diminish including the currently available frequency response capabilities, inertia, voltage regulation tools, reactive power support highlighted below (Figure 5).

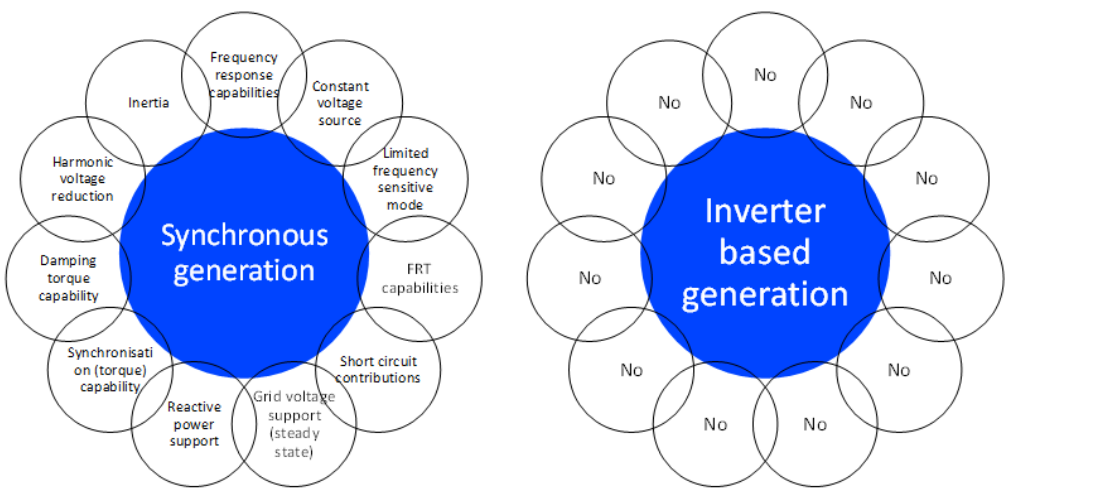

Figure 7. System Operation challenges as defined by GETCO on system strength parameters due to accelerated RE generation

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).

GETCO also highlighted that adoption of new technologies and rapid installation of new power system management tools will be required including grid ancillary services and grid supporting smart technologies, 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 and solutions

The existing Gujarat policies incentivise significant distributed solar deployment. GIZ estimates that in Gujarat about 75% of the solar rooftop capacity could be integrated without additional infrastructure cost. GIZ highlighted that the German rooftop experience with its over 1.8 million rooftop PV systems shows that distributed PV can support the low voltage network and support the grid with voltage stability and reactive power. In Germany solar PV generated 8.2% of gross electricity consumption in 2019, share of all RE sources was 43% in total generation. GIZ research shows that PV inverters available in the Indian market are capable of providing the reactive power support, and therefore the CEA connectivity regulation changes can unlock this potential going forward.

Flexibility from demand response

GETCO and SLDC both highlighted that demand side management, including agricultural demand shifting is already an important grid balancing tool and this is expected to be even more prominent in the future.

PGVCL highlighted the importance of agricultural demand in Gujarat, which in the PGVCL region represents 36% of total connected load and 30% of total consumption. PGVCL oversees over 50,000 new agriculture connections every year adding nearly 300 MW load in the system by use of conventional pump sets. There is also a potential for industrial demand response but it is significantly smaller.

Flexibility from conventional generation

GSECL (the state-owned generation company) presented its coal power plant flexibility objectives of shorter start up times, higher ramp rates (1% and 3%) and introduced pilots testing 55% operating minimums for older and 40% operating minimum for newer plants, which show significant improvement potential from the current rates of around 75% and 50-65%, respectively. The presentation also highlighted the importance of compensation for the investment needed to achieve these technical improvements and losses due to decreased efficiency and increased O&M costs.

Flexibility from Energy Storage

Gujarat currently has hydro plants that are planned to be converted into pumped hydro resources in the coming years. The workshop participants highlighted that in Gujarat there is no regulatory and tariff framework for storage at the moment, and thus there is a need for development of this framework.

Some study results were presented that cover the topic of energy storage with the aim to estimating the optimal amount of storage for Gujarat in the future. ISGF highlighted that its India storage roadmap's most ambitious scenario included 2.1 GW of batteries in Gujarat by 2032. World Bank also presented its ongoing Gujarat battery storage assessment project's preliminary results. The World Bank battery capacity estimate was based on the costs and benefits from Ramping support, Energy Arbitrage, and also includes the benefits from capacity deferral and loss reduction, the optimization was completed from both DISCOM perspective and consumer/regulatory perspective.

Ongoing Regulatory and Tariff reforms and Digitalization

RE policy implementation is highly supported by the state regulator GERC and as such it introduced new regulations designed to help system integration of RE, including:

- tariff system to compensate for financial impact of ramp up and down of conventional plants,
- load and forecasting regulations with no penalty for generators,
- investment in the transmission sector to promote RE in the remote and coastal areas,
- time of use tariff pilots.

The India Smart Grid Forum's (ISGF) ongoing Time of Use tariff study in Gujarat highlighted the minimum technical requirements: Advanced Metering Infrastructure, Energy Management Software and smart switches and devices. Furthermore, it emphasized the need for regulatory changes, the need for informing consumers and the request of consumers to fully understand the benefits for the tariff including exact impact on bills.

The GERMI annual financial model (presented at the workshop) of regulated electricity tariff in Gujarat shows that in the aggressive RE deployment scenario of 10 GW solar and 10 GW wind by 2023 the revenue gap would increase (to over 6% from 5%) with significant decrease of thermal generation (8 GW lower) and a very small 0.02 INR/kWh increase of tariffs.

3. Results of the IEA and CER power system modelling study

3.1 Modelling background and methodology

IEA and CER, IIT Kanpur started to develop the Gujarat power system model in coordination with Gujarat SLDC in July 2019. Following the data collection and model building phase, the preliminary results were presented during the Gujarat workshop in October 2020. Based on the workshop and the subsequent consultation calls as well as the numerous inputs, feedback and suggestions from local stakeholders – including GUVNL, GETCO, SLDC, GERMI, LBNL and IEX –the analysis has been finalized and detailed in the following sections.

To evaluate, in more detail, the impact of increasing renewables on the Gujarat power system, a detailed modelling study was undertaken. The study focuses on two time frames: a short-term perspective up to 2021-22 (2022) and a medium-term perspective up to 2029-30 (2030). The financial year 2018-19 (2019) is used as a validation year for the developed modelling framework. The purpose of the model is to evaluate the contribution of diverse flexibility options to address renewables integration challenges for Gujarat over the short- and medium-term. The approach taken uses production cost dispatch modelling for the three target years, with the capacity mix based on Gujarat government targets.

Horizon	Variable renewables share in capacity	Variable renewables share in generation
Validation (FY2018-19)	29%	12%
Short term (FY2021-22)	42%	20%
Medium term (FY2029-30)	71%	37%

Table 5. Variable renewables generation and capacity share by modelling year.

The modelling effort was undertaken in collaboration with the CER, IIT Kanpur, with separate models being developed in parallel by IEA and CER. The IEA model is developed in PLEXOS modelling software, while the CER model is developed in GAMS, allowing for cross-validation between the modelling approaches and different benefits from the two platforms to be accessed. CER also assisted with data collection and provided the load forecast. The results presented here are derived from the IEA PLEXOS model but have been developed in full collaboration with CER.

The model includes separate nodes for each DISCOM area in Gujarat (Figure 7), as well as a separate node for the Kutch region, which is a part of the PGVCL distribution license area, as this is a particularly renewables rich region that will host much of the renewables capacity in the state in the coming years. The model takes a 'contracted capacity' approach, so that all capacity contracted by Gujarat is represented in the model both from inter-state and intra-state plants, and capacity located in Gujarat but contracted by other buyers is excluded from the analysis. The external nodes connect only plants that are contracted by Gujarat. Short-term market purchases are also allowed at the external nodes but within the overall limits of transmission capacity.

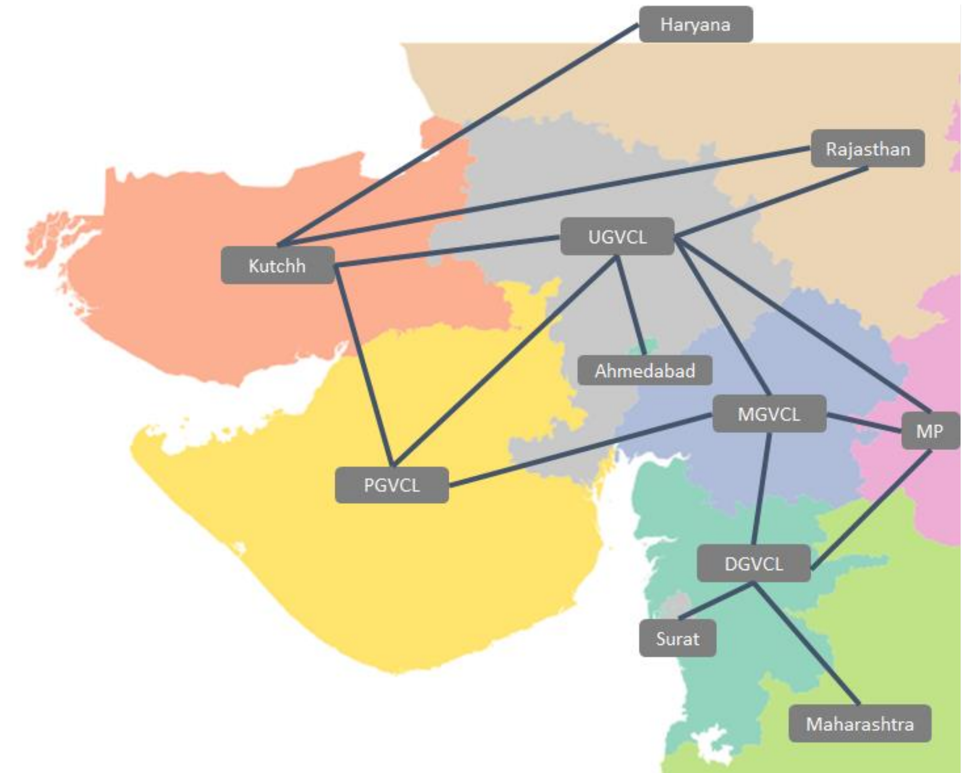

Figure 8. Gujarat Model structure

Model assumptions and inputs

- The dispatch is performed at hourly resolution, with existing capacity, capacity additions to 2022 and, plant-wise variable costs based on recent GERC tariff orders.
- Renewables deployment is based on Gujarat government targets. Plant retirements are included based on CEA plans, and plant-level operational parameters such as ramping limits and start-up time are derived from generic CEA data.
- Gas availability is based on historical availability for 2019 and 2022 and expected allotments for 2030.
- The hourly demand profile for all years is based on state-level demand for 2019, with disaggregation between DISCOM based on the annual DISCOM-wise demand from 2019. The impact of Covid-19 has been considered for demand forecasting.
- Future annual demand for the state up until 2030 is based on projections by the Centre for Energy Regulation (CER) and Energy Analytics Lab (EAL) at IIT Kanpur, taking into account the available projections from the state.
- All inter-state and intra-state transmission lines at a voltage of 400 kV or higher are mapped and included in the model.

- Renewables generation profiles are based on the ERA5 reanalysis dataset (CS3, 2017) and processed using NREL's System Advisor Model.
    - Maximum coincident generation relative to installed capacity at the DISCOM level is 76-78% for utility solar, 67-69% for rooftop solar, and 83-90% for wind.
    - At the whole Gujarat level in 2030, the overall capacity factors are 17% for solar and 24% for wind.

3.2 Changes and challenges in the future Gujarat power system

In the coming decade, the Gujarat power system will undergo a profound transformation. While the highest contribution of solar and wind to meeting hourly demand in 2019 was 39% (at 1 PM on 14 July), this is expected to rise as high as 80% in 2022, and could reach up to 160% of the demand during some hours by 2030.

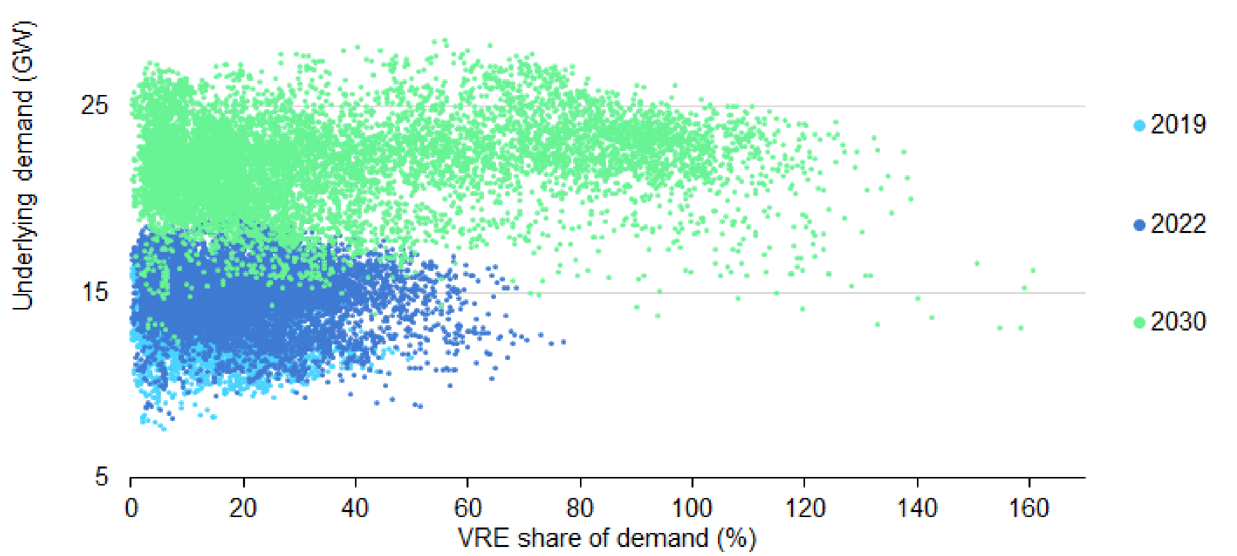

Figure 9. Hourly share of solar and wind generation as % of demand, IEA analysis

Today, the Gujarat system has zero curtailment of variable renewables generation, and this is expected to remain negligible in 2022. By 2030, in a case where there is no increase in flexibility and renewable energy is only to be integrated inside Gujarat, this would result in overall curtailment of around 7%. This highlights the need for an increase in power system flexibility with rising renewables share, to ensure cost-effective integration of variable renewable energy.

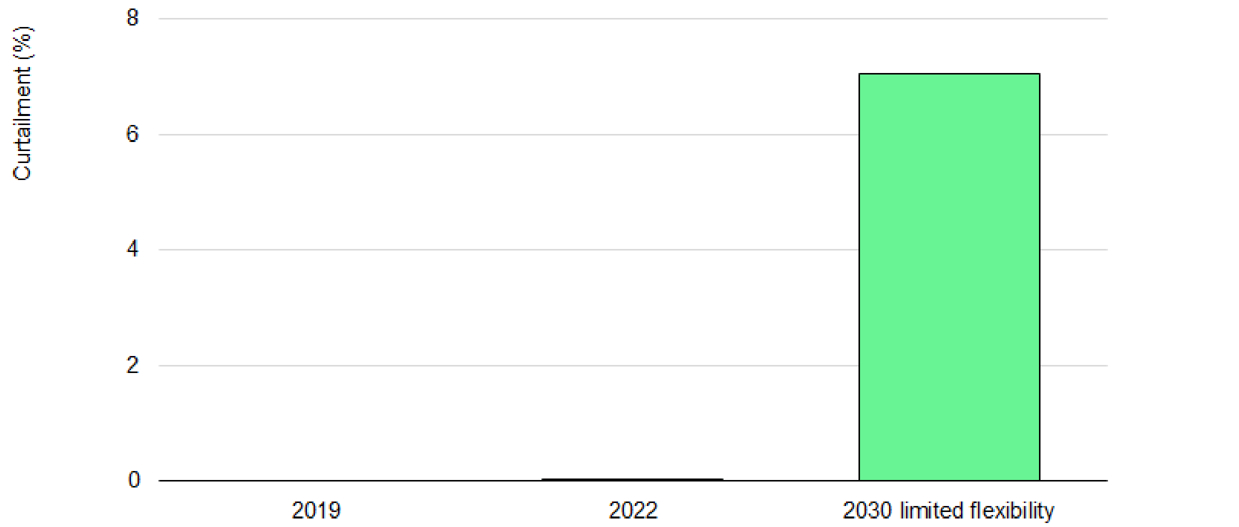

Figure 10. Curtailment of solar and wind in different years, IEA analysis

In addition, this large increase in variable renewables will result in deep impacts on the operation of conventional generators, particularly coal-fired generators. From the validation year, the average capacity factor (or plant load factor) for coal-fired generators drops fairly sharply from 79% in 2019 to 65% in 2022. This is, in large part, due to an increase in coal capacity from plants which are currently under construction or planned, as well as the must-run status of renewable energy which displaces conventional generation. The capacity factors of coal-fired generators are expected to bounce back slightly to 72% in 2030 due to a combination of load growth and no addition to conventional capacity, which slightly outweighs the impact of higher renewables contribution. At the same time, this relatively small change in capacity factors masks a dramatic shift in the operating regime for coal, as in 2030 the coal fleet is expected to spend more time at very low (e.g. below 50% of maximum fleet output) and very high output levels (e.g. above 90% of maximum output), resulting in increased operational stress (see Figure 10).

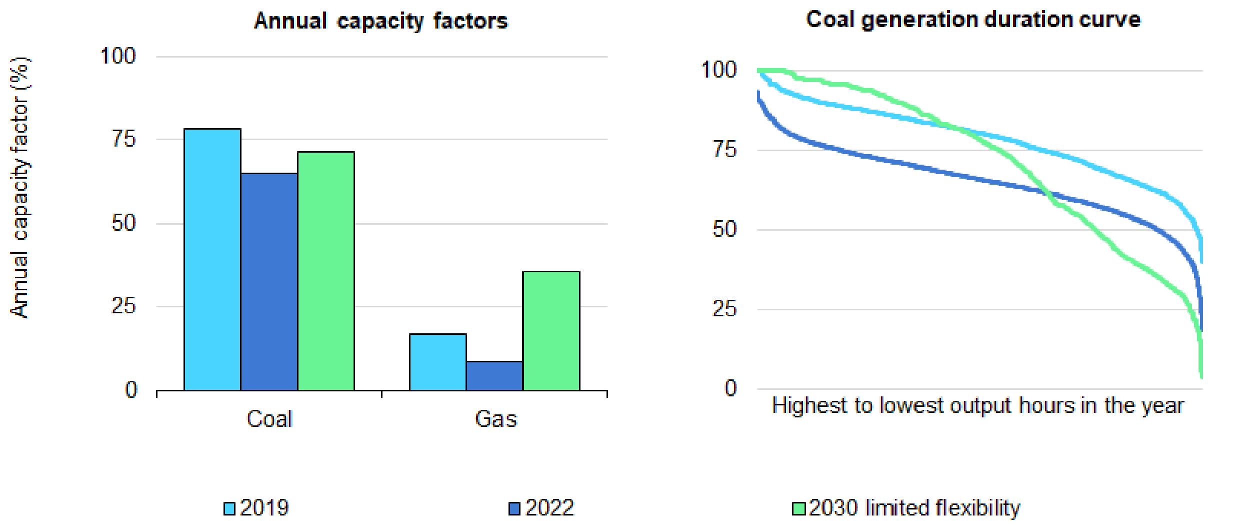

Figure 11. Capacity factors and coal generation curves in different years, IEA analysis

3.3 Overview of study years

Validation year (2019)

The validation results match closely to the historical Gujarat system with regards to the overall generation mix and seasonal availability of solar and wind. In today's system, power plants in Gujarat already need to operate more flexibly with increased ramping and partial loading to accommodate variable renewable generation. Some congestion is seen in the model on high voltage lines from Kutch, but without resulting in curtailment. It is important to note that local challenges during high VRE periods, such as evacuation of wind and solar from lower voltage levels or local system strength, are not captured in the modelling approach, which excludes low-level network.

Short-term horizon (2022)

To 2022, the existing flexibility in the Gujarat system is expected to cope well with the increasing share of wind and solar PV. With hourly shares as high as 80% of demand, relative to 50% in the base year, existing flexibility from dispatchable power plants is activated more, with a 43% increase in ramping from dispatchable technologies from 2019 to 2022. Line congestion from the Kutch region is similar to that seen in 2019 and curtailment remains close to zero.

Medium-term horizon (2030)

In the medium term, the continuing deployment of variable renewables will bring increased challenges at the state level. By 2030, VRE generation is expected to exceed electricity demand in Gujarat during many hours of the year, and system operation will be determined by the generation pattern of variable renewables.

3.4 Technical Solutions: key findings from flexibility scenarios

Based on the feedback from Gujarat local stakeholders as well as international experience, the IEA has developed a set of scenarios to illustrate the impact of different individual flexibility resources on the Gujarat power system in 2030. The key resources considered, in line with the workshop outcomes, are: demand response (agricultural demand), coal and gas power plant flexibility, and different storage resources (i.e. pumped hydro and batteries). In addition, a scenario was considered where some solar capacity is replaced by wind, to give a more even balance between wind and solar.

In the *limited flexibility* scenario, no new flexibility measures relative to 2019 are introduced, exports are not considered, and agricultural demand scheduling follows the existing night-time pattern. In this case, Gujarat would experience operational challenges including variable renewables curtailment of around 7%. In practice, there are multiple flexibility options that can help to integrate VRE generation locally in Gujarat, and of course it will also be possible to export renewables during certain hours.

The *plant flexibility* and *higher wind share* scenarios result in a slightly lower curtailment level close to 6% and in the agricultural demand shift scenario the curtailment level reduces to below 3%. In addition, three scenarios with either 1, 2 or 4 GW of battery storage (each with storage duration of 4 hours) were considered. In these scenarios, curtailment declines to as low as 2% for the case with 4 GW of storage. And finally, when looking at a combined application of the most promising flexibility resources, curtailment can be shown to be almost completely avoided (see Section 3.4.5). In the following sub-sections we describe each of these scenarios individually.

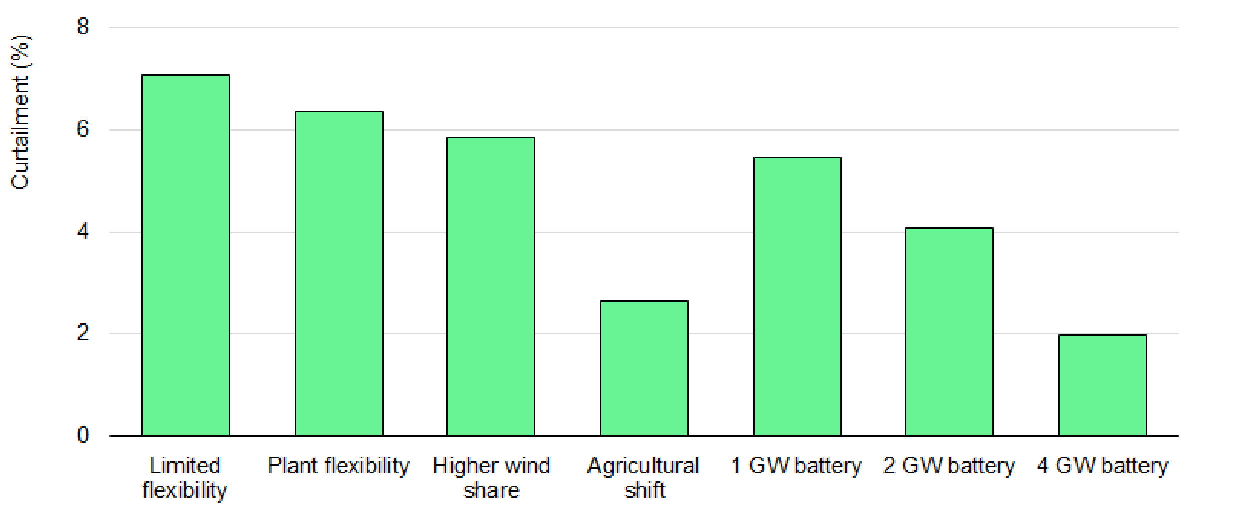

Figure 12. Curtailment of solar and wind in different scenarios, Source: IEA analysis

3.4.1 The demand side is a key source of low cost flexibility for integrating variable renewables in Gujarat

Gujarat's power demand is dominated by industrial use (around 60%) while agricultural demand represents around 20%, and residential and commercial demand the remaining 20%. All demand types can be a useful source of system flexibility, but in Gujarat the most promising demand side flexibility providers are agricultural users, followed by industrial demand response potential.

Agricultural demand is already an important source of power system flexibility in Gujarat today, with agricultural pumping loads scheduled in 8-hour windows and concentrated overnight. This has the combined benefit of ensuring that agricultural pumping coincides minimally with peak demand, while also supplementing lower overnight demand, allowing conventional plants such as coal-fired generation to maintain a more stable operation.

By 2030, the overnight scheduling of agricultural demand will no longer be optimal due to the higher PV generation in Gujarat, however agricultural demand will be able to be shifted to the daytime to align with high solar output hours (existing schemes to facilitate this in Gujarat are discussed below). In the *agricultural shift* scenario, this reduces curtailment to less than 3% (relative to 7% for *limited flexibility*), while also reducing unit starts by 39% for the coal and gas fleet. In addition, this results in around a one-third reduction in market purchases from other states, for an overall variable cost reduction of nearly 11% (with market purchases priced at $75 USD/MWh). Note that the total system cost, including renewables tariff cost, is not included in the reported operating cost as the modelling takes an overall social welfare perspective[1], and from this point of view these costs are sunk investment costs.

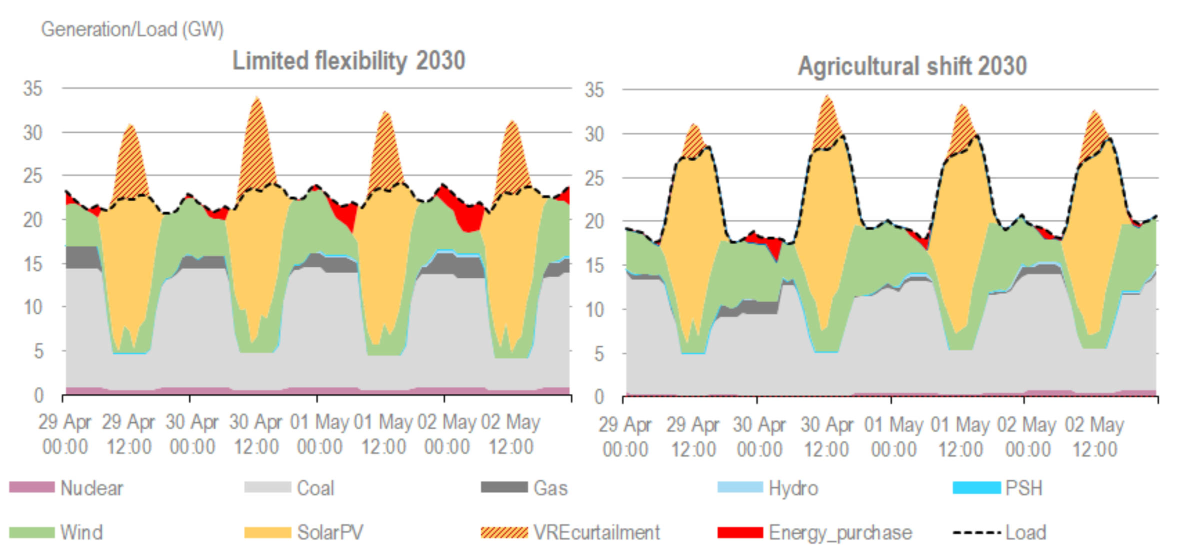

Figure 13. Impact of agricultural demand shift, Source: IEA analysis and analysis by Khanna, 2020

[1] The social welfare perspective focuses on total cost to society rather than financial flows between entities.

3.4.2 Power plant flexibility helps to avoid curtailment and reduce operating costs

Power plant flexibility is another important consideration, and includes faster ramp rates and lower minimum stable levels. Plant-level ramp rates are predominantly relevant on sub-hourly scales, so faster ramp capabilities are not a focus for the hourly model presented here. On the other hand, 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, and can be captured in the hourly modelling. For the base flexibility case, the minimum stable level assumed for central coal plants was 55%, in line with the current requirement in India. New plants were also assumed at 55%, and for state level plants, 75% was assumed, with 40% for gas CCGT. In the flexible case, central and new plants were reduced to 40% and state level plants to 55%. The impact of the power plant flexibility case in 2030 is a relatively modest reduction in curtailment (from 7.0 to 6.4%) and reduction in variable operating costs of 1.2%.

3.4.3 Energy storage allows high solar output during the day to be used during peak periods, reducing curtailment and avoiding costs from fuel and market purchases

Energy storage, such as batteries and pumped storage hydropower 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.

In order to evaluate the impact of pumped storage hydro (PSH) on system with otherwise limited flexibility resources, a scenario is considered where PSH is included in the limited flexibility case, from both the Kadana hydro power station (242 MW) and the SSP power station, which has developments currently ongoing to establish pumped mode (16% of 1200 MW allocated to Gujarat, and 192 MW capacity modelled). In this case, curtailment is reduced by 0.5%, market purchases by 4% and variable operating costs by 1%.

Including a 4 GW, 4-hour duration battery into the limited flexibility case has a larger impact due to both the large battery size and higher efficiency of the battery relative to the pumped storage plants (81% round trip efficiency for batteries relative to 60% efficiency for Kadana and 75% for SSP). In the 4 GW battery scenario curtailment is reduced to 2%, market purchases are around one quarter less and variable operating costs are reduced by around 7% including the cost of market purchase.

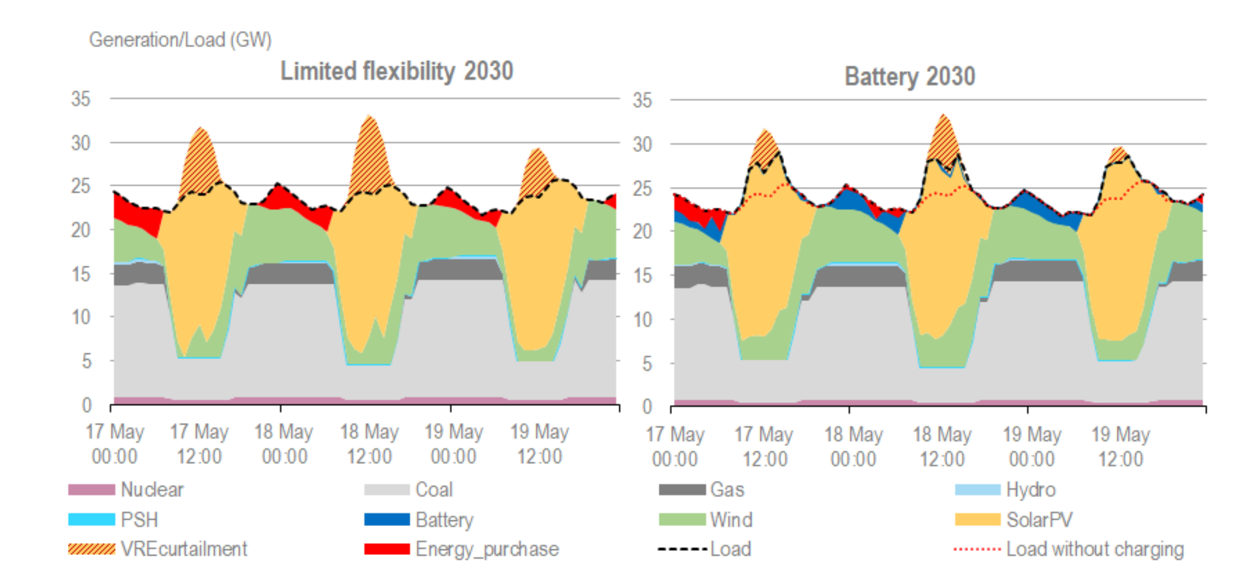

Figure 14. Impact of batteries, Source: IEA analysis

Further scenarios were also tested with smaller batteries of 1 and 2 GW capacity (4-hour duration), which when included in the limited flexibility case reduce curtailment to 5.4% and 4.1% respectively, and reduce variable operating costs including market purchase by 1.9% and 3.7% respectively.

3.4.4 A higher share of wind smooths the daily generation profile from variable renewables

Due to the falling costs of solar generation and relatively good solar resource in India, solar growth is expected to dominate renewables deployment in the coming years. At the same time, as solar generation increases, it does present specific integration challenges due to the concentration of generation in the middle of the day. For the base case, the proportion of wind and solar in the Kutch hybrid park[2] was set to reflect the balance in the rest of the state, with 7.2 GW of solar capacity and 2.8 GW of wind capacity . In order to explore the potential benefit of a more balanced mix between wind and solar generation, a higher wind scenario was tested with 5 GW each of solar and wind capacity in the Kutch hybrid park.

This results in a smoothing of average output across the day, with an increased contribution to the evening hours and a reduction in the sharp output peak seen in the middle of the day in the base case. On the other hand, the seasonal pattern of variable renewables availability is not improved by the increased wind generation. In the base case a peak in supply is seen during May-June-July followed by a fall-off during October-November when load is at its peak, which is not mitigated in the high wind case. Nonetheless, the increased output of wind and smoother daily distribution results in reducing curtailment to 5.9%, and a 5% reduction in variable operating costs including market purchase.

[2] The mix of solar and wind to be developed in the Kutch hybrid park has not yet been fixed in government plans.

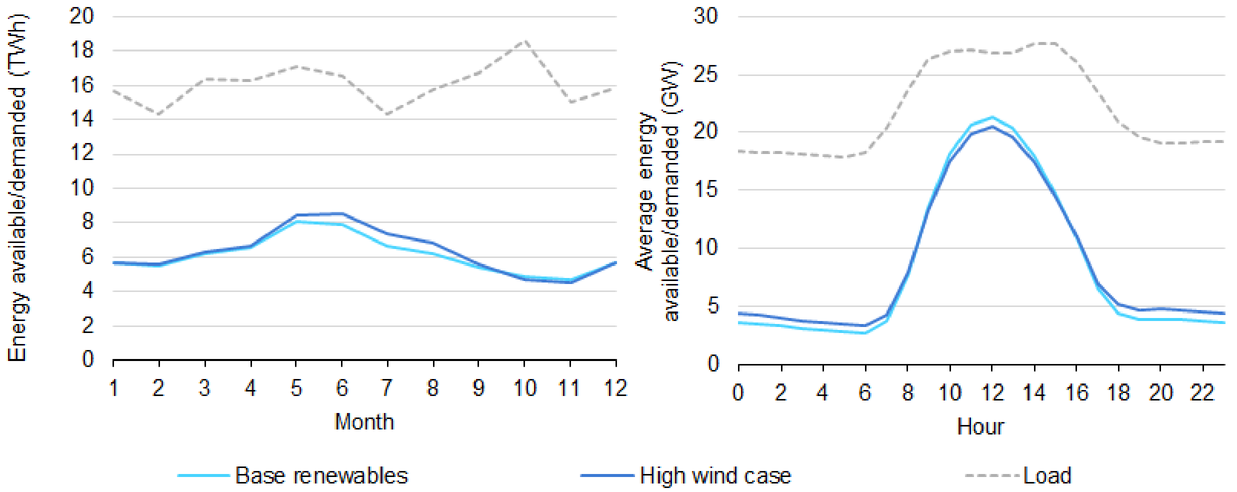

Figure 15. Impact of more wind deployment, Source: IEA analysis

3.4.5 Combined flexibility options allow effective integration of renewables in Gujarat

In the above scenarios, each flexibility option has been considered in isolation in order to allow their relative impacts to be evaluated separately. In addition, several scenarios have been tested with multiple flexibility options so that their combined contributions can be tested. Agricultural flexibility is included in all these cases, as it was shown to be one of the most effective flexibility measures from both a technical and cost perspective. Scenarios including a combination of agricultural demand response with plant flexibility, higher wind share, and battery deployment, illustrate that there are multiple pathways to reduce curtailment to 1% or below and provide further reductions in operating costs.

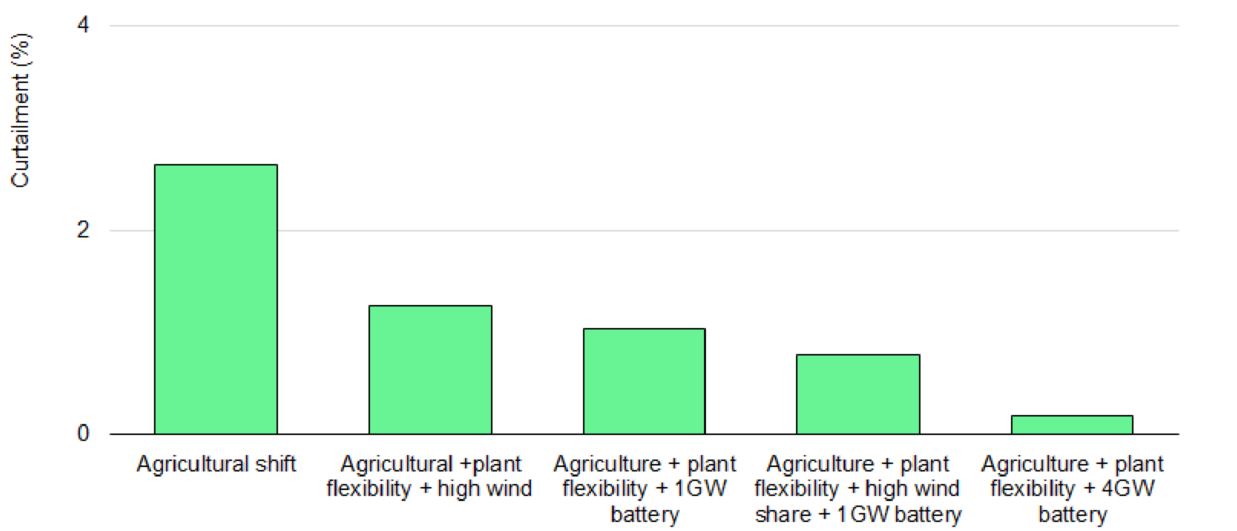

Figure 16. Curtailment of different combined flexibility scenarios, Source: IEA analysis

4. Policy, market and regulatory solutions for higher shares of RE

There is an agreement across all stakeholders about the importance of the policy, market and regulatory framework to unlock the technical flexible resources detailed in chapter 2 and chapter 3. This chapter highlights key elements of the existing Gujarat policy framework and brings relevant international examples.

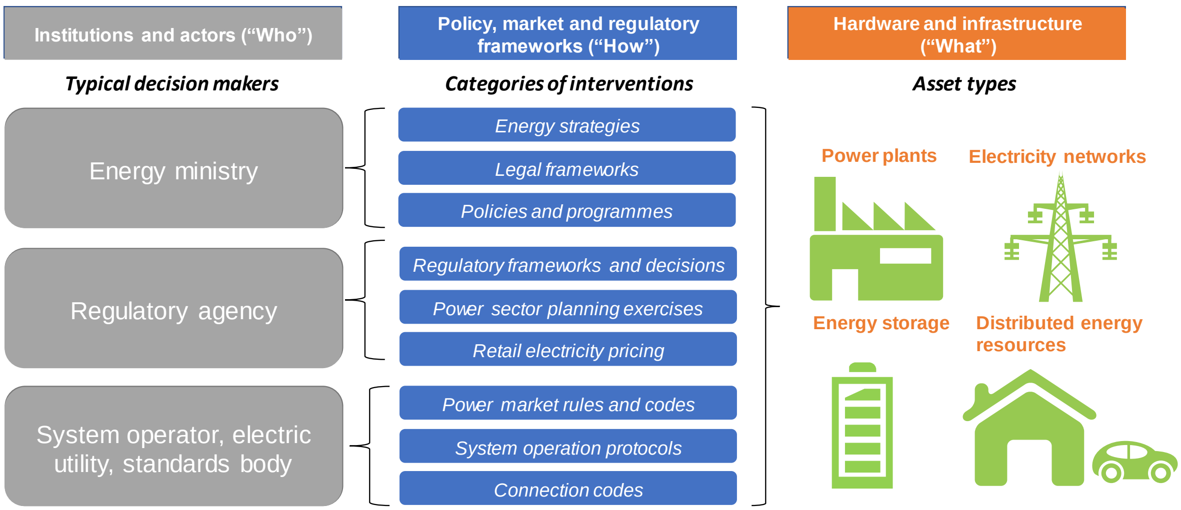

Figure 17. Power system flexibility embedded in the policy framework, Source: IEA analysis

4.1 Demand side policies in Gujarat

The current policy and regulatory environment in Gujarat is already highly supportive of RE integration. While Chapter 2 highlights the most important regulatory innovations implemented by GERC, this chapter focuses on some of the most important demand-side policies to unlock the deployment of flexible resources in the State of Gujarat. The Jyoti Gram Yojana is an initiative of the Government of Gujarat started in the year 2003 to ensure 24-hour availability of quality three-phase power supply to rural areas of the state. This policy enabled rural agricultural consumers to shift to electricity-based pumping systems, reducing their expensive dependence on diesel-based pumps. Additionally, the policy enables monitoring, pricing and rationing of power consumption separately for the agricultural, residential and industrial sectors, making agricultural demand shifting one of the most important power system balancing tools today.

Gujarat was one of the first states in the country to implement energy efficient pumps in the agricultural sector. More than 100,000 agricultural electricity connections were involved in the policy every year since 2016. Agricultural electrification was further supported through the installation of smart/pre-paid meters in the Integrated Power Development Scheme (IPDS).

The State policy Ujjwal DISCOM Assurance Yojana (UDAY) with the Government of India was instrumental in reducing the electricity rates for agricultural consumers and strengthening fuel security through coal swapping, and reduction in aggregated technical and commercial losses from the DISCOM side.

The Kisan Suryoday Yojana was launched in October 2020 in Gujarat with the aim of providing 16 hours of power supply to farmers in the state every day. This scheme intends to provide day-time 8-hour long power supply for irrigation between 5:00 AM and 9:00 PM in two shifts. Today 8-hour power is provided on a rotational basis in day and night hours. The key objectives are to reduce the night-time power scheduling of agricultural load, to improve life style of farmers and to reach maximum utilisation of solar power.

Distributed solar initiatives include both agricultural solar pump and rooftop solar policies in Gujarat. One of the most significant policies, the national KUSUM (Kisan Urja Suraksha evam Utthaan Mahabhiyan) policy is an important driver of solar of pump deployment and also enables farmers to sell solar generated electricity to the grid.

The national KUSUM scheme has three components, the Component A involves setting up 10 GW of decentralized ground-mounted, grid-connected solar projects of up to 2 MW. The Component B plans to install 1.75 million standalone solar-powered agricultural pumps of individual capacity up to 7.5 HP. And the Component C, Solarize, plans to install 1 million grid-connected agriculture pumps of individual capacity up to 7.5 HP. Gujarat state allocated INR 795.8 million (~$11.09 million) for grid-connected solar microgrids for agricultural pump sets.

A critical renewable policy in the agriculture sector is the solar pump set scheme that gives beneficiaries subsidized solar water pumps sets of 3, 5 and 7.5 HP (horse power). The state government has approved the budget for installation of 4,000 solar pumps. In 2018 the scheme was piloted in 33 districts to enable 12,400 farmers to generate solar power and to use that part of that power for irrigation. The rest of the generated power can be sold as a surplus to the grid for INR 7 (US$0.10) per unit for seven years and INR 3.50 (US$0.05) per unit for the remaining years. Under the initiative, farmers contribute 40% of installation costs, while central and state government will subsidize 60% of costs.

The above schemes have multiple benefits in that they enable farmers to irrigate their fields during the daytime, provide and additional source of revenue to the farmers and provide farmers incentives for reducing groundwater consumption (Shah *et al.*, 2014, DSUUSM, 2018). The impact of solarization of agricultural pumps on the electricity system is uncertain and would depend on the design of the scheme. For example, if farmers feed electricity into the grid during peak load hours it could cause a mismatch in demand and supply.

4.2 Rooftop solar regulatory innovation for the future system

This section focusses on international insights on rooftop solar, related integration challenges and related policies and regulations.

Today, rooftop PV capacity in Gujarat sits under 1 GW, but by 2030 this is planned to increase to over 6 GW. With this increase, the impact of solar PV at the distribution level will become much more significant, with implications both for demand forecasting and local grid management.

According to the SLDC 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 monitored in real time, but the distribution company takes into account rooftop generation as part of demand forecast submitted to SLDC, similarly to captive generation. In the future the impact of lack of visibility can lead to significant uncertainties of net demand forecasts illustrated in Figure 17.

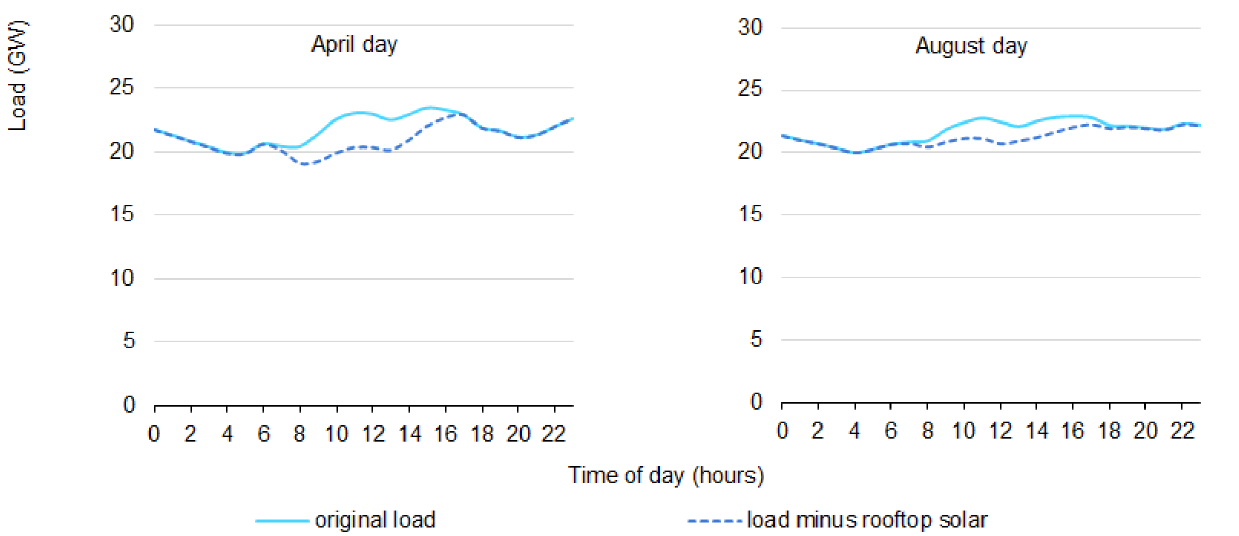

Figure 18. Illustration of impact of rooftop solar on Gujarat's daily demand in 2030 at different times of year, Source: IEA analysis

IEA analysis envisions significant growth of rooftop solar capacity in Belgium, Germany and Australia, reaching over 20% of total capacity by 2024 (Figure 18). International experience of Germany, UK, Australia and US Hawaii suggests that visibility of rooftop PV can be ensured through connection requirements embedded in DISCOM and/or transmission connection codes.

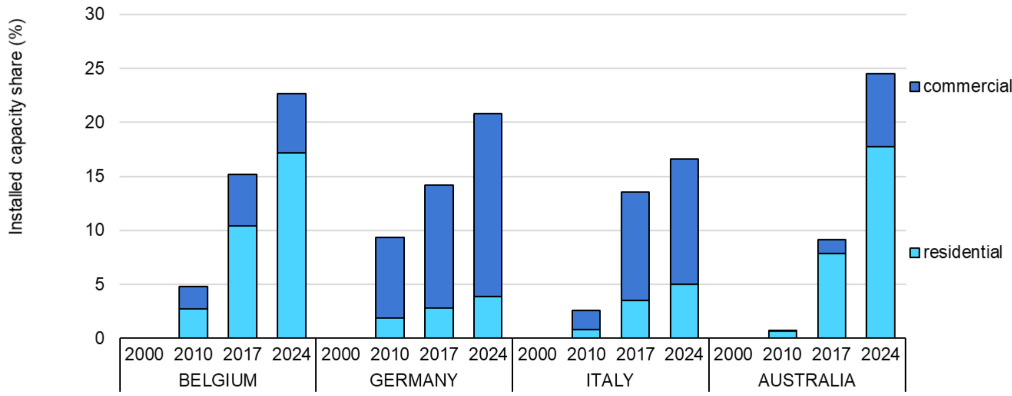

Figure 19. Rooftop solar capacities (residential and commercial) for developed countries from 2000 to 2017 and projected capacities for 2024, Source: IEA analysis

The Australia example highlights how the country manages rooftop solar visibility and forecasting related challenges and local network issues. More specifically in Australia, with 2.5 million rooftop solar systems with a combined capacity of over 18.5 GW by the end of 2020, the visibility of existing installations including their size and their location is managed through use of the DER registry portal managed by AEMO. This register doesn't provide real time information. For real time data on rooftop solar generation smart metering would be a prerequisite. However smart meter data collected in every household doesn't directly translate into real time data for DISCOMs. Even in Queensland, where every household has a smart meter and 40% of all houses have rooftop solar, real time data is not available to the distribution company. The smart meters submit data on a 24-hour timeframe basis. This data provides sufficient insight for the distribution companies for the forecast of rooftop solar, as rooftop solar output has proved to be fairly predictable depending on known weather patterns.

The other key rooftop solar challenge observed in Australia includes local network congestion, high local voltage levels (over 245V) and reverse flows to the distribution systems during the day when demand is low. They experience more reverse flows, particularly as the cost of rooftop PV has decreased and households are installing larger 6-7 kW systems. One of the solutions being piloted is the so-called dynamic operating envelope. This software-based solution limits the export to the distribution system to maximum 10kW per house during system stress. National rollout and development of detailed rules and regulations are currently ongoing.

In Australia rooftop solar currently receives a fixed (non-dynamic) feed-in tariff. But in the future moving to 5-minute settlement on wholesale markets will also provide future opportunities.

Based on the Australia example the State of Gujarat can consider 2 actions to improve visibility of rooftop solar in the state, as the first step. GERC could appoint an entity to develop distributed solar registry platform for all DISCOMs for solar pump and 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. In parallel, DISCOMs can 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.

4.3 Gujarat prices and tariffs in wider India and international context

The current electricity pricing and tariff design in Gujarat - and more widely in India - is significantly influenced by the government’s 100% electrification objective, which provided access to electricity to most of the communities in India by 2019. Additionally affordability of electricity is another key objective behind tariff design.

As a result, current household electricity prices in India are lower than the OECD average in nominal terms. However, when adjusting for purchasing power, which better accounts for spending on electricity as a share of Indian household income, household prices are amongst the highest in the world. This is despite the fact that India – like other emerging and developing economies – has higher end-user prices for more energy-intensive industrial consumers in order to cross-subsidise the lower tariffs paid by low-income residential and agricultural users.

Industrial electricity prices in India at 99 USD/MWh are significantly higher than residential prices at 69 USD/MWh (on a nominal basis). The high industrial prices drive large volumes of industrial users in India to open access contracts with prices that are on average 20% to 30% lower than utility prices. Prices also vary, not just among end users, but also across states, where consumers in some states pay five times more for their electricity than their counterparts in neighboring states.

Gujarat has one of the highest residential prices across India's States, while industrial and commercial prices in Gujarat are well below the prices in the average Indian state. Prices for agricultural users are also low compared to other states.

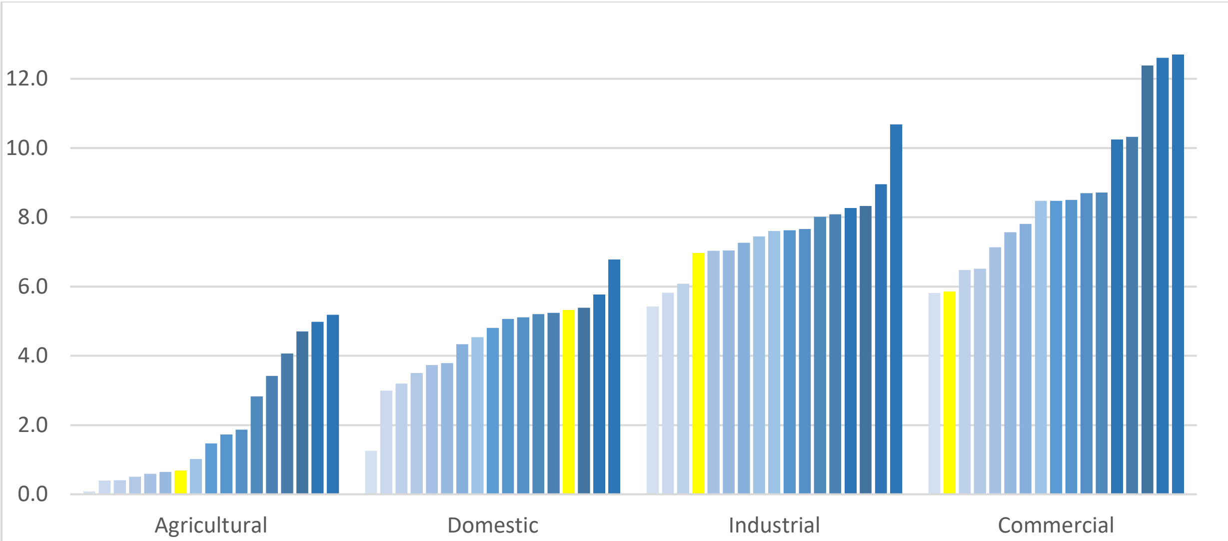

Figure 20. End user electricity prices (in INR per kWh) in Gujarat (in yellow) and in other states in India, Source: IEA analysis based on PFC data, calculated from each state's DISCOMs' revenue per kilowatt-hour for each category of consumer

These prices are average effective end user prices calculated based on regulated electricity tariffs charged by DISCOM s. The tariffs include fixed and variable charges (related to generation costs including fuel costs) and other non-tariff incomes, such as wheeling charges, open access charges, fuel adjustment surcharges etc. In Gujarat (similarly to most states in India) tariffs are not cost reflective due to the cross-subsidy system, application of national and state taxes and further subsidies provided to DISCOMs.

4.3.1 Tariff reforms for the future system

In the future electricity prices and tariff design can become one of the most important tools to enable more demand side flexibility in Gujarat. Electricity tariff design and tariff options may need revision with increasing share of renewables as the timing of the system use for different consumers will become critical, especially in high solar generation times. 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.

Gujarat state tariff reforms can include expanding the time-of-day pricing to more customers, adjustment of peak tariff slots, introduction of time of use tariffs (TOU) and switching more users to default time dependent tariffs.

Additionally, tariff reform 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 line with international market reforms described in Section 4.5, where the overarching long-term objectives are that all different flexible resources (both demand and supply side) compete on an equal footing.

An international example of how tariff system can better align solar generation with peak demand is the Time of Use (TOU) rates policy change in 2020 in California. The TOU rate have been available as a choice for more than 10 years but very few consumers actually switched to use these rates. Required by the regulator in 2020 the state's three investor-owned utilities have shifted their 22.5 million residential consumers to default TOU rates, making the TOU rate the default choice as opposed to the previous flat rate. During the pilots the utilities demonstrated that for every 10% increase in price ratio of the TOU rates, peak demand decreased with 6.5-11%. The policy change was made available by the widespread use of residential smart meters, something not readily available in Gujarat today, but something that is set to change with the current studies look at TOU reforms in Gujarat.

4.3 International examples of regulatory and market innovation

In Gujarat in Phase 3 there is an increasing role emerging for flexibility from pumped hydro, grid-scale battery storage, smart charging of EVs and for operational security there is role for for synthetic inertia. International experience highlighted in this section 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 GERC in Gujarat. More specifically storage, including batteries, face barriers to enter and compete in the current regulatory setup, for example: would battery investors be eligible for fixed cost payments (such as capacity and availability payments internationally) as thermal assets? At the same time the development of new ancillary services products and ancillary services market provide an opportunity to consider all the new technologies from the start.

Additionally, Gujarat 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 (wholesale and retail) market barriers of new technologies is an important ongoing task worldwide. Figure 20 shows how different countries are deploying various flexibility technologies and related policies in different Phases of System Integration.

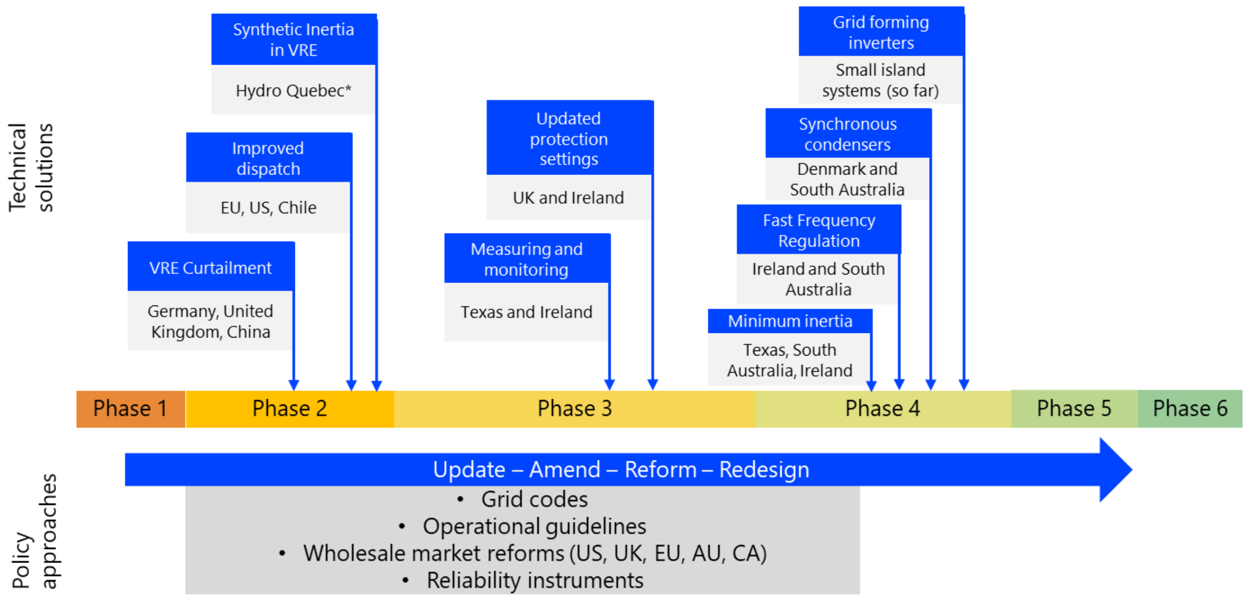

Figure 21. International insights into VRE integration solutions, Source: IEA analysis

For example, the U.S. Federal Energy Regulatory Commission (FERC), which regulates wholesale electricity markets and the high-voltage transmission system, has issued Order 841 instructing system operators to review their market rules and remove unnecessary barriers to energy storage participation. This rule opens the doors for all types of energy storage resources sited anywhere on the power system to participate in energy, capacity and ancillary services markets under FERC's jurisdiction. 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 large, conventional 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 to participate in wholesale markets, even in cases when this threshold was reduced to 1MW, this still excludes 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 Gujarat

The following roadmap summarizes the key system integration challenges and solutions highlighted in the report connecting them with a timeline and the system integration phases and most relevant stakeholders.

	Gujarat Solar and Wind Integration Roadmap	**Phase 3**	**Phase 4**	
	Technical and policy solutions	By 2022	By 2030	Most relevant stakeholders
Operations	REMC implementation for improved forecasting of solar and wind			SLDC
	Continue with existing agricultural demand scheduling in the short term, and support schemes to transition to day-time scheduling as solar output increases. Toward 2030 transition from current demand shift practice to demand response with financial compensation for pro-active farmer flexibility.			SLDC, DISCOMs, GERC
Grid codes and planning	Design and implement technical flexibility requirements for new solar and wind investments.			GERC, GETCO, SLDC
	Review transmission investments needs for 2030 targets			GETCO
	GERC to appoint an entity to develop distributed solar registry platform for all DISCOMs for solar pump and 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.			GERC, DISCOMs SLDC
	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, GUVNL

	Consider that contracting processes for new large scale renewable capacity consider the time-value of energy, so that not only Levelized Cost of Energy is considered but also the value energy has at different times of day or seasons.			GUVNL, DISCOM, GERC
Power market and regulation	Develop view and policy on solar and wind curtailment (must run status) and a compensation framework for future curtailment.			GERC, GETCO, SLDC
	Prepare for synthetic inertia or synchronous requirements. Study how inertia providing assets may be sourced in Gujarat (such as utility purchases or market incentives).			GERC, SLDC
	Consider introduction of new ancillary services and design of ancillary services market			GERC, SLDC, GUVNL
	Further expand regulatory framework to compensate coal power plant investors for increased coal power plant flexibility			GERC
	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.			GERC, SLDC, private sectors
	Review existing power trading (banking) with other states and consider how to expand trading activity to provide regional balancing of solar and wind resources.			GERC, GUVNL
Retail	Continue ongoing TOU review and develop policies for roll out of minimum technical requirements, including smart meters			GERC, DISCOMs
	Progressively move different consumer types to default TOU rates			DISCOMs, GERC

Table 6. Solar and Wind Integration Roadmap for Gujarat, Source IEA Analysis, 2020

Acknowledgements & Preparation of the workshop and report

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Annex 1. Workshop participants and <u>speakers</u> (speakers underlined)

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<u>Edmund Andrew</u>	<u>Arup</u>
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Kanti BHUVA	GERC
<u>Akhilesh Magal</u>	<u>GERMI</u>
Yashraj Gore	GERMI
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<u>BA Gandhi</u>	<u>GSECL</u>
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Kartik Veerakumar	IEA
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Paolo Frankl	IEA
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Piotr Bojek	IEA
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Sumit Verma	IIT Kanpur
Madhav Sharma	IIT Kanpur
Aprajita Salgotra	IIT Kanpur
Shambhavi Mishra	IIT Kanpur
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Shuvam Sarkar Roy	India Smart Grid Forum
Bindeshwary Rai	India Smart Grid Forum
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Ashwin Kumar	Indian Institute of Technology, Kanpur
Nausheen	Indian Institute of Technology, Kanpur
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Anand Singh	ISGF
Bala Karnam	ISGF
Yoshiro Kaku	NEDO
Chris Abraham	NIL
Rakesh Sarwal	NITI Aayog
Rajnath Ram	NITI Aayog
John Dulac	OECD
Upendra Behera	OERC
JJ Gandhi	PGVCL
Vivek Pandey	POSOCO
Ashwin Gambhir	Prayas (Energy Group)
Srihari Dukkipati	Prayas (Energy Group)
Rasika Athawale	Regulatory Assistance Project (RAP)
Dheer Patel	Regulatory Assistance Project (RAP)
Chetna Hareesh Kumar	Sciences Po
Uma Kumar	Self-employed
Abhishek Kaushik	TERI

Name	*Organisation (A to Z)*
Moumita Bhattacharya	UK Foreign, Commonwealth and Development Office
Ramit Debnath	University of Cambridge
Mani Khurana	World Bank
Tirthankar Mandal	WRI

Annex 2. References

Gujarat Workshop agenda and presentations

https://www.iea.org/events/power-system-transformation-workshop-2-state-of-gujarat

Gujarat policies

Research _Report_on_Energy_Sector_in_Gujarat.pdf (guvnl.com)

Indias-Vast-Potential-in-Solar-Powered-Irrigation-.pdf (ieefa.org)

PM Modi Launches 'Kisan Suryoday Yojana' for Farmers in Gujarat (saurenergy.com)

Govt expands scope of PM-KUSUM for harnessing solar energy by farmers, Energy News, ET EnergyWorld (indiatimes.com)

Maharashtra Workshop agenda and presentations

https://www.iea.org/events/maharashtra-power-system-transformation-workshop

IEA (2017), *Getting Wind and Sun onto the Grid: A Manual for Policy Makers*, Paris, www.iea.org/publications/insights/insightpublications/Getting_Wind_and_Sun.pdf.

IEA (2018), System Integration of Renewables, IEA, Paris

https://www.iea.org/reports/system-integration-of-renewables

IEA and 21CPP (2019), Status of Power System Transformation 2019 – Power System Flexibility, Paris

https://webstore.iea.org/status-of-power-system-transformation-2019

IEA Commentary (2019), U.S. regulatory innovation to boost power system flexibility and prepare for ramp up of wind and solar

https://www.iea.org/commentaries/us-regulatory-innovation-to-boost-power-system-flexibility-and-prepare-for-ramp-up-of-wind-and-solar

IEA workshop on Technical secure integration of large shares of converter based power sources, March 2020

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

IEA Future of Cooling Report, 2018

https://www.iea.org/reports/the-future-of-cooling

Khanna, T. 2021. Optimizing agricultural demand response for reducing costs of renewable energy integration in India. SSRN Working paper

Shah, T., Verma, S., Durga, N. (2014). Karnataka's smart, new solar pump policy for irrigation

CS3 (Copernicus Climate Change Service) (2017). ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate . Copernicus Climate Change Service Climate Data Store (CDS), accessed January 2020. https://cds/climate.copernicus.eu/cdsapp#!/home*DSUUSM (Dhundi Solar Energy Producers Cooperative Society), (2018). Tri-Annual Report 2015-2018* https://hdl.handle.net/10568/103434

India CEA report, Gujarat capacity data, November 2020

https://npp.gov.in/public-reports/cea/monthly/installcap/2020/NOV/capacity2-Western-2020-11.pdf

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
GETCO	Gujarat Electricity Transmission Company
GERC	Gujarat Energy Regulatory Commission
GSECL	Gujarat State Electricity Generation Company
GUVNL	Gujarat Gujarat Urja Vikas Nigam Limited, is the Gujarat parent company for state owned electricity companies
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	levelised cost of electricity
Mahagenco	Maharashtra generation company ltd.
MERC	Maharashtra Electricity Regulatory Commission
MNRE	Ministry of New and Renewable Energy
MSEDCL	Maharashtra State Electricity Distribution Company ltd
MSETCL	Maharashtra State Electricity Transmission Company ltd
NITI Aayog	National Institution for the Transformation of India
OECD	Organisation for Economic Co-operation and Development
PGCIL	Power Grid Corporation India, Ltd.
PGVCL	Gujarat distribution company (Paschim Gujarat Vij Company Limited)
POSOCO	Power System Operation Corporation, Ltd.

PPA	power purchase agreement
PSH	pumped-storage hydro electricity
PV	photovoltaic
RAP	Regulatory Assistance Project
RE	Renewables (solar, wind, hydro, biomass etc)
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 center
21CPP	21st Century PowerPartnership