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Roadmap for a Net Zero Power Sector in Gujarat

October 2025

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BESS – Battery Energy Storage Systems

CEEW – Council on Energy, Environment and Water

CUF – Capacity Utilization Factor

DANIDA – Danish International Development Agency

DISCOM – Distribution Company

GCAM – Global Change Assessment Model

GEDA – Gujarat Energy Development Agency

GUVNL – Gujarat Urja Vikas Nigam Limited

LEAP – Low Emissions Analysis Platform

PPA – Power Purchase Agreement

SDG – Sustainable Development Goals

UNEP CCC – United Nations Environment Programme Copenhagen Climate Centre

VRE – Variable Renewable Energy

GEDA
ગુજરાત ઊર્જા વિકાસ એજન્સી
GUJARAT ENERGY DEVELOPMENT AGENCY
A Government of Gujarat Organisation

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FOREWORD

Gujarat stands at the forefront of India's clean energy revolution. This leadership is driven by visionary governance, bold policy frameworks, and a deep-rooted commitment to sustainability. As the State Nodal Agency for the Ministry of New and Renewable Energy and the State Designated Agency for the Bureau of Energy Efficiency, GEDA has played a catalytic role in shaping Gujarat's renewable energy landscape. From pioneering Asia's first solar park in Charanka to transforming Gandhinagar into a model solar city, our journey has been defined by innovation, inclusivity, and impact.

This roadmap for a Net Zero Power Sector in Gujarat builds on that legacy. It offers a rigorous, evidence-based framework to guide the state's transition toward a decarbonized power system. The strategy is anchored in renewable energy, electrification, and resilience. With electricity demand projected to grow fivefold by 2045, the roadmap outlines how Gujarat can meet this surge through clean energy sources, modern infrastructure, and strategic investments. It also highlights the importance of integrating solar, wind, and emerging technologies such as battery storage and green hydrogen to ensure energy security and grid stability.

The roadmap recognizes the social, economic, and environmental dimensions of Gujarat's energy transition. It addresses critical challenges such as land availability, grid integration, financial risks, and supply chain vulnerabilities. Moreover, it emphasizes the need for a just and inclusive transition that creates green jobs, empowers communities, and ensures equitable access to clean energy.

GEDA is proud to support this roadmap as a strategic instrument that aligns Gujarat's energy ambitions with its climate commitments and development goals. With nearly ₹6 lakh crore in investment needed by 2030, the roadmap identifies diverse financing mechanisms. These include green bonds, public-private partnerships, and international climate finance. It also calls for policy harmonization, capacity building, and diversification of the energy basket to sustain momentum and deepen impact.

As Gujarat moves toward its 100 GW renewable energy target by 2030 and Net Zero by 2070, this roadmap serves as a guiding light for policymakers, industry leaders, researchers, and citizens. It reflects Gujarat's unwavering resolve to lead India's energy transition through scale, strategy, innovation, and shared purpose.

Together, let us power Gujarat's future with clean energy, climate resilience, and inclusive growth.

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1. Introduction

The UNEP Copenhagen Climate Centre (UNEP CCC) initiated a project for undertaking 'Net Zero Strategy' in one state of India. The state and national implementation partners were identified in 2023 through a competitive process. The project is funded by DANIDA and is jointly delivered by the Global Centre for Environment and Energy (GCEE), Ahmedabad University and the Council for Energy, Environment and Water (CEEW). The project approach creates an evidence base through detailed scientific assessments and stakeholder consultations (See Figure 1). This evidence base is reported in the in the report, published in April 2025 “Assessment of Net Zero Scenarios for Gujarat” (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025). The “Roadmap for a Net Zero Power Sector” complements the report and takes a deep dive into the power sector, which emerged as the most important sector for achieving Net Zero by 2070 in Gujarat.

Evidence Base

1. **Net Zero scenario-based assessment covering key mitigation sectors using energy system models**
   - Updation of state-level CO_2 inventory
   - Desk Review of scenario-based assessment for of low carbon and Net Zero Scenarios
   - Analysis of Net Zero CO_2 emission pathways at state-level till 2070 using LEAP and GCAM model
2. **Sustainable Development Impact assessment** of Net Zero pathway using a qualitative approach (quantitative assessment whereever possible).

Roadmaps

3. **Prepare technology roadmaps** to guide the implementation of the Net Zero strategy, including
   - **Prioritise the technologies** relevant to the state based on Net Zero Assessment and SD impact assessment
   - **Barrier analysis and measures** to address barriers for the technologies
   - Prepare a draft roadmap with actions needed in the short term (until 2030) and thereafter to achieve Net Zero by the target year
   - Organise a **workshop for validation** of the roadmap

Stakeholder consultations and capacity building within line ministries on net-zero pathways

Figure 1: Project Approach for Net Zero Strategy.
Source: Authors’ analysis.

Since 2010, Gujarat has made significant progress on renewables deployment, leading from the Gujarat Solar Policy, 2009, which was among the most ambitious policies in the country. Achieving Gujarat's net-zero targets necessitates substantial electrification of end-use consumption in all sectors, especially industry and transport. However, this electrification will only contribute to net-zero emissions if the electricity is sourced from renewable energy, reducing reliance on high-emission fuels.

If the projected electrification materialises, Gujarat's total electricity demand is expected to increase 5-fold from 2025-2045. In 2024, renewable energy contributed approximately 32% of the state's total power generation. Despite ambitious strides in renewable energy penetration, future decarbonization would require further policy pushes to scale up and integrate renewable energy in the state.

As a key pillar in Gujarat’s net zero transition, this report provides a roadmap for Renewable Energy in the Power Sector. The roadmap builds on the larger assessment of Net Zero Scenarios for Gujarat and aims to provide the following:

- Targets and milestones for the Power Sector
- Key actors and agencies involved in implementing the roadmap
- Guidance and policy recommendations for different actors
- Finance and enabling conditions, including infrastructure

Section 2 "Pathways for Power Sector Decarbonisation" covers targets for renewable energy based on the modeling results reported in the “Assessment of Net Zero Scenarios for Gujarat”. While focusing on the long-term Net Zero target, the report identifies actions that can be taken in the short-term, i.e., until 2030 to medium term, i.e., until 2035 and further up to 2045 for enhancing renewable energy capacity and generation in the state. The year 2045 also aligns with the state’s long-term vision of a “Viksit Gujarat” by 2047 (Government of Gujarat, 2024b).

Section 3 "Barriers to Scaling Up Renewable Energy Generation and Integration" focuses on barriers to RE scale up in the power sector and Section 4 "National and State Level Policies and Implementation" deals with the policy environment at the national and state level facilitating the scale up. Subsequent sections deal with the power infrastructure required in Gujarat and investments needed to achieve the vision of a Net Zero power sector.

2. Pathways for Power Sector Decarbonisation

Electricity demand by sectors

Total emissions for Gujarat in 2023 was 261 $MtCO_2e$, of which energy accounted for 67% (178.8 $MtCO_2e$) (Climate Change Deparment & Gujarat Energy Development Authority, 2025). Gujarat's vision for 2047, laid out in the Viksit Gujarat strategy document, aspires for Gujarat to become a $3.5 trillion economy by 2047 (Government of Gujarat, 2024b). This aspiration along with higher future urbanization and per capita income will lead to a steep increase in electricity demand . A detailed assessment of pathways for the energy sector, including the power sector, was undertaken using Global Change Analysis Model (GCAM) and Low Emissions Analysis Platform (LEAP) models as part of the project assessing Net-Zero scenarios for Gujarat (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025). Results from both these models show the electricity sector to be at the heart of the transition. Electricity demand rises significantly in the future as electrification is the principal method of decarbonisation. Moreover, this electricity is principally sourced from renewable energy, entailing significant increase in RE-based generation. In this roadmap we have only used results from GCAM since analysis of additional infrastructure needs and investment and financing analysis done in Section 6 "Investment Requirement" are based on the GCAM model.

In 2025, around 48.2% of Gujarat's electricity demand was from the industry sector (80.6 TWh), followed by the building sector (62.9 TWh) and the agriculture sector (20.7 TWh). In both the reference and net zero scenarios (See Figure 2), the electricity demand grows by 62% between 2025 and 2030. By 2040, the electricity demand in the reference scenario goes up to 517 TWh, with building (42%) and industry (32.1%) being the two largest demand sectors. Demand also increases within the agricultural sector due to the electrification diesel-based irrigation pump sets and the introduction of new solar-based pumps. Until 2040, both the electricity demand as well as the share of demand between the net-zero and reference scenario remains largely similar. In fact, demand is slightly lower in the NZ scenario in the industry sector due to higher energy efficiency measures. In 2045, demand in the NZ scenario becomes slightly higher than the reference scenario, as end-use sectors electrication gathers speed.

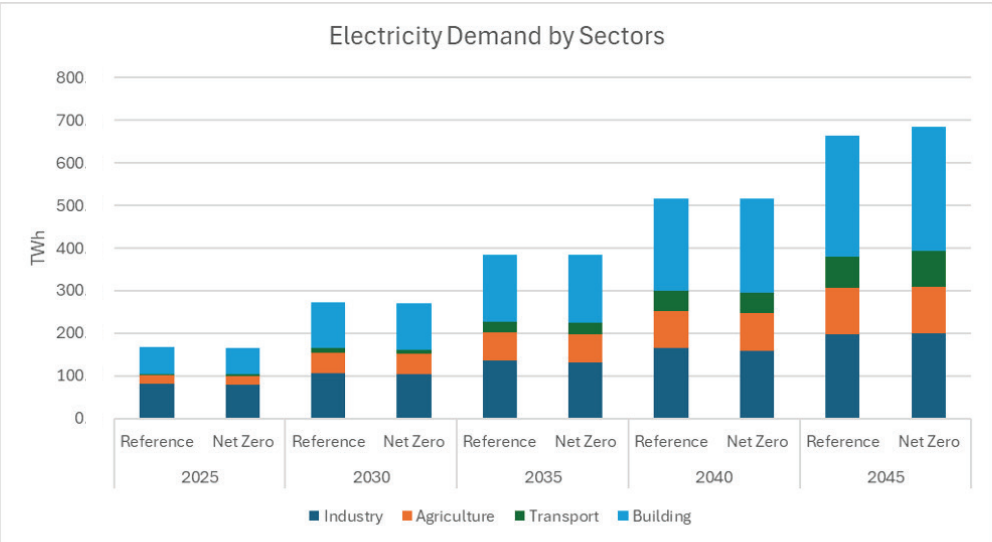

Figure 2: Electricity demand in end-use sectors from GCAM (in TWh).
Source: (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025)

Electricity generation

In 2020, the majority of the total electricity generation was from coal (63%), followed by gas (16%), wind (12%), solar, hydro and nuclear (3-4% each).

In the reference scenario, the total electricity generation grows by 134% between 2020-2025 and 64% between 2025-2030. By 2030, electricity generation reaches 455.6 TWh (See Figure 3a) and 71% of it will come from renewable sources. The cumulative electricity generation grows to 634 TWh and 965 TWh by 2035 and 2045, respectively (See Figure 3a). If we look at sources of electricity generation, electricity from coal-based plants declines to 19.5% of Gujarat's total power generation in 2045. Meanwhile, shares of solar, wind and nuclear-based generation will be 51.6%, 20.5% and 7.2%, respectively, in 2045.

Figure 3a

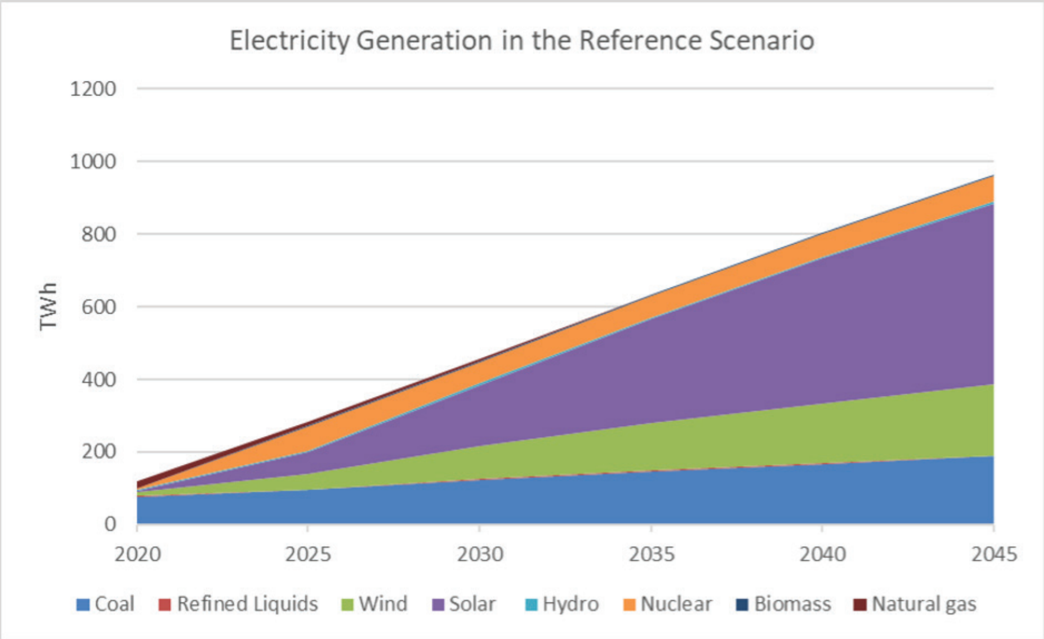

Figure 3b

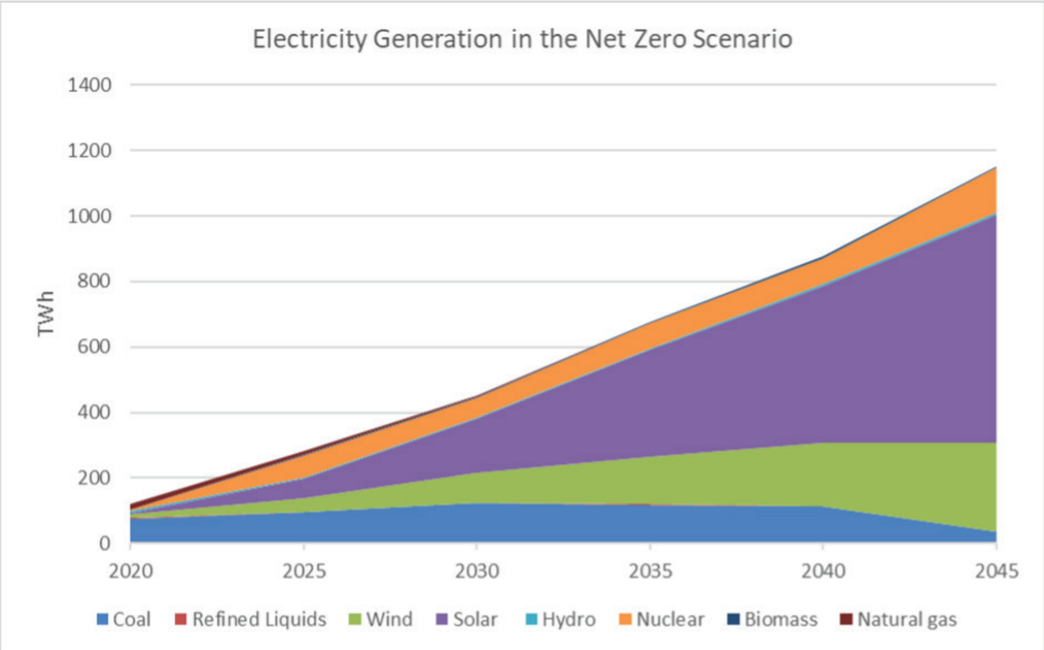

Figure 3a and 3b: Electricity generation (TWh) by source in reference and net zero scenario from GCAM. Source: (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025).

In the Net Zero Scenario, the total electricity generation in 2025 is 282 TWh (See Figure 3b) which increases to 451 TWh by 2030 and 1153 TWh in 2045. The share of coal-based electricity generation increases from 94.5 TWh in 2025 to 123.7 TWh by 2030 and gradually declines over the next 15 years to 35.25 TWh by 2045. In the NZ scenario, it is assumed that no new coal power plants are built beyond 2030. In 2045, the major share of power generation in Net Zero scenario is using solar (60.5%) and wind (23.5%), followed by nuclear (12%).

It is important to note that until 2045, Gujarat, similar to the current situation, remains an electricity surplus state - producing more electricity than required to fulfill its own demand and exporting additional power generation.

Electricity generation capacities

In the reference scenario, the total installed power generation capacity reaches 99.6 GW in 2025 and 190GW in 2030. In 2030, nearly 80% (~152 GW) of this capacity will be from renewable sources. Between 2030 and 2040, wind and solar-based capacity grows by 125% and 86%, respectively as these become cheaper compared to alternatives. Coal-powered power generation capacity, on the other hand, grows by 39% in this period. By 2045, power generation capacity, will increase to 428.3 GW, with almost 88% of the share coming from renewable energy sources (See Figure 4).

In the net zero scenario, the electricity generation capacity grows to 188 GW in 2030. The share of RE grows rapidly in this period due to favorable pricing. Due to regulation for no new coal based capacity post 2030, RE based generation capacity between 2030 and 2035 would double to 280 GW with ~90% of RE share in cumulative capacity of the state. This is due to cheaper solar and wind based power generation. Between 2030 and 2040, solar, wind and nuclear based capacities grow by 173%, 120% and 31% respectively, whereas fossil based capacities show a decline. The total electricity generation capacity of Gujarat will reach 537 GW, with almost 98% RE-based power generation in the state by 2045 (See Figure 4). In 2045, the share of solar and wind within the overall state's capacity will reach 71% and 24%, respectively, with fossil-based capacity reduced to merely 11.18 GW (See Figure 4).

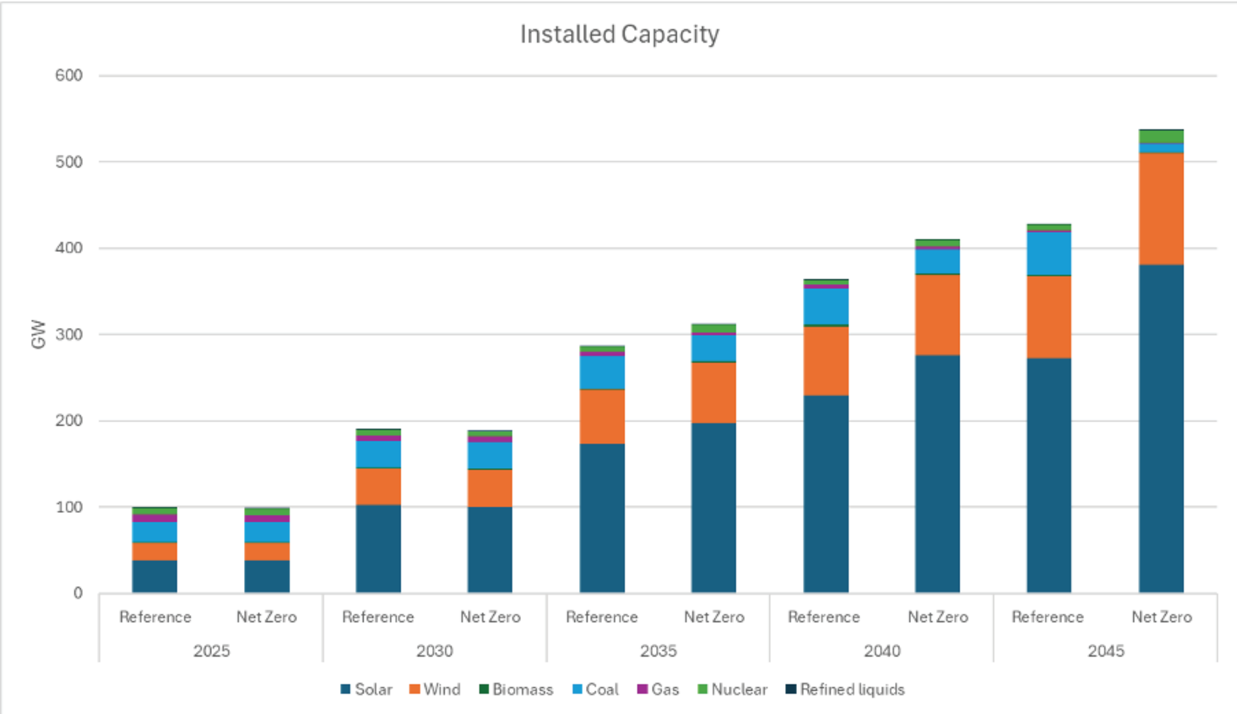

Figure 4: Installed Capacity (GW) by source in reference and net zero scenario from GCAM.
Source: (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025)

Implications for Power sector Emissions and Sustainable Development

Gujarat's direct emissions from the power sector was 66.79 MtCO_2e in 2020. This is expected to grow by 121% to 148 MtCO_2e by 2045 in the reference scenario. However, in the net zero scenario, the direct emissions due to electricity generation go down by 70% to 19.5 MtCO_2e by 2045.

Increased electrification coupled with increasing share of renewables will result in wide ranging impacts on the economy, environment and society. A significant increase in renewable energy share in the total energy mix in future will enable Gujarat to achieve targets under SDG 7 (Clean Energy) as well as SDG 13 (Climate Action). This will also contribute to other sustainable development goals potentially through investments in infrastructure for example electric vehicle infrastructure in cities, innovation and boost domestic manufacturing.

For the power sector, this could generate new employment opportunities in renewable energy. Our study shows between 3.8 to 6.1 million new green jobs could be generated by 2045 due to RE transition in Gujarat's power sector. However, there will be loss of jobs in the traditional fossil fuel based power sector. In particular, the Net Zero scenario shows a net loss of 381,000 jobs until 2045 (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025).

3. Barriers to scaling up renewable energy generation and integration

Although ambitious renewable energy targets and efforts are being made at both the national and state levels, a Net Zero pathway will require unprecedented expansion of renewable energy. However, such a transition may entail technical, financial, resource or other challenges. This section outlines key barriers identified through detailed individual consultations with key stakeholders representing the government and private sector. It further discusses measures to address these challenges. The following are the key barriers identified:

1. Resource Constraints

(a) Land constraint: Large-scale renewable energy projects, particularly wind and solar, require vast land areas,often conflicting with agricultural, social, and ecological needs. Land near major demand centres (such as industrial and urban areas) is scarce and under competitive pressure, limiting the availability of suitable land for renewable energy projects and hindering their scale-up (IRENA, 2018; NITI Aayog, 2015). Additionally, despite significant investments, these projects offer limited local employment, reducing community support and increasing the risk of social and biodiversity trade-offs (Industrial Automation India, 2022; Times of India, 2025).

Table 1: Land footprint (Acre/MW) of projects.

Source Type	Lower Limit	Upper Limit	Median
Thermal	0.67	1.09	0.88
Nuclear	0.20	0.66	0.60
Hydro	0.50	10.00	5.00
Solar	3.90	4.10	4.00
Wind	1.50	2.00	1.75

Source: Ministry of Power, Government of India, 2023

(b) Water: Overall water consumption increases in future for all scenarios due to the increase in electricity generation. Transitioning to renewable energy reduces overall water consumption compared to thermal power plants. Managing the increased water demand will be essential for balancing Gujarat's energy needs with its limited water resources.

2. Variability Constraints

(a) Reliability: The variability of solar and wind energy—on daily and seasonal scales—limits their ability to provide a stable supply, making them unreliable for meeting consistent electricity demand, restricting the extent to which they can replace conventional power sources (Painuly & Wohlgemuth, 2021).

(b) Grid Integration and infrastructure:

(i) Sudden drops or spikes in renewable energy generation can strain existing grid infrastructure, leading to power disruptions and increased operational costs. To mitigate these risks, renewable plants must operate alongside conventional sources to maintain a stable base load, but limited forecasting accuracy hampers this balance and increases the likelihood of grid instability (Che et al., 2025; Painuly & Wohlgemuth, 2021).

(ii) Storage infrastructure could mitigate variability, but current grid infrastructure is not designed to support large-scale storage integration. This limits the ability to store and dispatch renewable energy effectively (Jafrizadeh et al., 2024).

(c) Financial Constraints:

(i) Renewable energy suppliers face penalties under the deviation settlement mechanism included in agreements with DISCOMs if they fail to meet annual supply targets due to variability, increasing financial risk for developers.

(ii) Without timely integration of storage infrastructure there is likelihood of renewable energy curtailments leading to financial risks for developers.

(d) Climate Change Impacts: The increasing frequency of extreme weather events and shifting seasonal patterns due to climate change further exacerbate the variability of solar, wind, and hydro generation, introducing unpredictable supply challenges and complicating grid management (Cronin et al., 2018; Solaun & Cerda, 2019).

3. Economic and Market Barriers

(a) Unit Energy Cost: One of the primary financial challenges is aligning Unit Energy cost expectations (IRENA, 2018). Supporting infrastructure like storage and transmission increases the unit cost of renewable energy, reducing its market competitiveness. While state buyers expect prices on par with conventional energy, this lowers returns for developers and discourages investment (IRENA, 2018). The lack of mechanisms such as carbon markets or IRECs further limits revenue options. Additionally, pressure to keep costs low can compromise infrastructure quality and investor confidence, while the political sensitivity of higher energy prices complicates efforts to align cost expectations essential for long-term sector growth.

(b) Delayed Power Purchase Agreements: An estimated 40–60 GW of renewable capacity is under construction or proposed without matching power purchase agreements (PPAs), creating investment uncertainty. Without guaranteed PPAs, developers face difficulty in securing financing. There are several causes for the delayed PPAs such as Shifting unit energy cost discovery guidelines, future cost uncertainties, demand-supply mismatches, and DISCOMs' financial instability together hinder the signing of long-term renewable energy agreements. (Construction World, 2024; The Economic Times, 2024), which need to be addressed in order to facilitate scale-up.

(c) Open Access: In the absence of demand from state DISCOMs, renewable energy developers may sell power in open markets, but several constraints limit this option. DISCOMs often prohibit the sale of surplus energy under long-term agreements, while STUs restrict grid connectivity for excess capacity. Developers also incur additional wheeling charges when using state distribution networks, raising unit costs and deterring buyers (NITI Aayog, 2015). Moreover, mismatched pricing expectations and the uncertain financial credibility of market buyers further increase investment risks and reduce the attractiveness of open market sales for developers.

4. Policy and Regulatory Constraints

(a) Misalignment Between Central and State Policies: There is a misalignment between the central aims, targets and guidelines and state-level regulation in certain states. While central guidelines provide a standard framework, state-level deviations can create uncertainty in unit energy cost discovery and tendering processes, affecting market confidence and delaying project development (NITI Aayog, 2015).

(b) Reactive and Short-Term Policies: Industry experts believe that current renewable energy policies are reactive in nature with focus on short-term goals and cost reductions. Long-term considerations, such as sector sustainability, supply chain resilience, end-of-life asset management, technological standardisation, and cybersecurity risks, receive limited attention, undermining the sector's long-term growth.

5. Technical Barriers

(a) **Connectivity:** Efficient grid connectivity is critical for renewable energy deployment, but financial constraints on state utilities and limited infrastructure in remote project locations often delay grid expansion and integration, creating operational bottlenecks (Gorman et al., 2025; RPS Group, 2025; Yuen, 2024).

(b) **Efficiency:** Renewable energy plants typically operate at a capacity utilization factor (CUF) of 15-25% (wind and solar) compared to 80–90% for conventional plants (Solarnplus, 2024). This affects the resource requirements and operational efficiency of these plants.

6. Other Barriers

(a) **Capacity Building:** The specialized skills required for renewable energy infrastructure development and operation are in short supply. Low unit energy costs further limit the ability of developers to invest in training and workforce development, reducing operational efficiency. Additionally, Lower-level government officials involved in implementation often face lack of technical knowledge and updated information on government aims and targets, causing friction, delays and inefficiencies in project execution (NITI Aayog, 2015).

(b) **Supply Chain and Manufacturing:** India relies heavily on imports for key materials such as lithium, cobalt, and nickel (Hund et al., 2023; IEA, 2021; Zero Carbon Analytics, 2024). Limited domestic production capacity and supply chain vulnerability expose the sector to geopolitical risks, creating supply insecurity.

(c) **Other Renewable Sources:** Approximately 90% of India's renewable energy generation is from solar and wind (MN&RE, 2025). Diversification into alternative sources such as bioenergy, geothermal, and offshore wind is needed to reduce variability and improve supply resilience. Over-dependence on solar and wind increases grid instability and limits the flexibility of the renewable energy sector.

Mitigation Measures for Renewable Energy Scale-Up:

To overcome the identified barriers and accelerate the scaling up of renewable energy in Gujarat, a multi-faceted approach addressing technical, financial, regulatory, and operational challenges is essential. The following key mitigation measures are recommended:

1) Land Availability and Local Impact

(a) **Land Optimization:** Encourage hybrid renewable projects (e.g., wind-solar hybrids) to maximise land utilization and reduce land footprint. Promote co-located solar projects with agricultural activities to reduce competition for land and increase local acceptance. Increase focus on decentralised power generation and consumption.

(b) **Policies facilitate land availability and reduce social friction:** Provide upfront Government support to identify and facilitate access and connectivity to suitable land. Introduce lucrative compensation policies to gain local support and minimise social friction. Understand the potential viability of mechanisms to share revenue with local communities and create employment opportunities to increase community support and minimize social friction.

2) Variability Constraints

(a) **Advanced Forecasting:** Develop and deploy improved technology for better forecasting and managing supply-demand fluctuations and mismatch to reduce grid imbalances and improve supply stability (IRENA, 2018).

(b) **Storage Solutions:** Promote large-scale deployment of battery storage and pump storage sites to mitigate supply variability and provide grid stability.

(c) **Diversification:** Encourage the development of alternative renewable sources, such as bioenergy, geothermal, and offshore wind, to reduce overdependence on solar and wind and enhance supply resilience.

3) Economic and Market Barriers

(a) **Cost-Competitiveness:** Assess potential for providing targeted subsidies and tax incentives and, conversely, introducing an additional tax on coal-based electricity production to reduce the cost of renewable energy production and storage infrastructure.

(b) **Guaranteed Offtake:** Establish financing mechanisms such as low-cost financing and green bonds to mitigate financial risk to ensure revenue security for developers and improve bankability.

(c) **Cost Stability:** Introduce mechanisms for predictable and improved financial compensation through unit energy cost for developers to reduce investment uncertainty and improve market confidence and sustainability (IRENA, 2018).

(d) **Market Instruments:** Develop mechanisms for developers to benefit from other instruments, such as carbon markets and International Renewable Energy Certificates (IRECs), to create additional revenue streams and improve financial viability (IRENA, 2018).

(e) **Open Access Facilitation:** Introduce mechanisms to facilitate open access to make renewable energy more competitive in open markets. The mechanisms should focus on reducing power wheeling charges, improving credit ratings of open market suppliers, and transparent and simple open access frameworks (NITI Aayog, 2015).

4) **Policy and Regulatory Measures**

(a) **Harmonised Policies:** Improve alignment between central and state-level policies to create a stable and predictable regulatory environment, particularly for unit energy cost discovery and tendering. Develop a coherent policy framework covering all renewable sources (solar, wind, bioenergy, offshore, etc.) to prevent fragmentation and streamline processes (NITI Aayog, 2015).

(b) **Long-Term Strategy:** Shift from a short-term and reactive approach focused on cost minimisation to a long-term, proactive, and consultative approach aimed at the sustainability of the sector. It should focus on increasing and strict implementation of renewable purchase obligations, end-of-life asset management, supply-chain resilience, cyber/digital security, technology standardisation, incentivising innovation and technological advancements, etc. (IRENA, 2018).

(c) **Decentralised Systems:** increase focus on decentralised renewable power generation to reduce pressure on central grid infrastructure as well as land resources and to improve energy access.

5) **Technical Barriers**

(a) **Innovation Incentives:** Establish funding and incentives for research and development (R&D) in advanced renewable technologies, grid management, and storage solutions. Promote industry and academia collaboration to accelerate R&D in renewable energy storage and grid management.

(b) **Grid Expansion:** Accelerate grid infrastructure upgrades for seamless integration of renewable projects (NITI Aayog, 2015).

6) **Capacity Building**

(a) **Informed leaders and Skilled Workforce:** Establish training programs and certification schemes to build a specialised workforce for leading, planning, regulation, installation, operation, and maintenance of renewable energy projects. Provide technical training and capacity-building programs for state and local government officials to improve technical expertise and project execution efficiency. Encourage industry-academia partnerships to develop expertise in renewable technology and grid management. Develop dedicated centres for renewable energy research and training to build technical capacity (IRENA, 2018; NITI Aayog, 2015).

4. National and State level Policies and Implementation

Renewable Energy Targets

India has taken an ambitious target of turning Net Zero by 2070, aiming to have 500 GW of RE capacity by 2030 (Ministry of Environment, Forest and Climate Change, 2023). India's NDC aims to achieve 50% cumulative electric power installed capacity from non-fossil sources. India's total renewable energy capacity (as of Nov 2024) has crossed the 200 GW mark (PIB Delhi, 2025).

The Wind Energy Program is to achieve 60 GW of wind energy capacity by 2030 (Ministry of New and Renewable Energy, 2018), and the Small Hydro and Biomass program aims to achieve 15 GW capacity by 2022 (Ministry of Power, 2024). India's Green Hydrogen policy aims to achieve 5 million tonnes of green hydrogen production capacity annually and 125 GW RE capacity by 2030 (Government of India, 2023).

To complement these targets at the state level, Gujarat's Renewable Energy (RE) Policy 2023 aims to scale up solar, wind and hydro energy to achieve 50% of its cumulative power installed capacity from RE sources by 2030. In 2024, Gujarat had 30 GW of RE capacity, and the target for Solar and Wind energy-based power generation is to maximise utilisation of the state's Solar+Wind potential (179 GW) (Government of Gujarat, 2023). To achieve this an estimated additional investment of Rs 5000 billion is needed (Government of Gujarat, 2023). In this regard, Gujarat has formulated specific policies for RE based technologies

The recently launched PM Surya Ghar Muft Bijli Yojana (2024) aims to promote small-scale decentralised residential rooftop solar installations and help contribute to overall scale up to 100 GW by 2030 (Ministry of New and Renewable Energy, 2025). Gujarat's State Action Plan on Climate Change (SAPCC) states Gujarat's vision in being a frontrunner in renewable energy growth with a target of 68 GW by 2030, through initiatives like installing solar panels on Narmada canal, building Gandhinagar into a modern solar city and no new thermal power plants in the state (Climate Change Department, 2021).

The Gujarat Small Hydel policy (2016) aims to promote small hydropower projects on canals and rivers and create 25 MW of RE power capacity by 2023 (Energy and Petrochemicals Department, Government of Gujarat, n.d.). Gujarat's Waste to Energy policy aims to develop 100 MW of power generation capacity from municipal solid waste (MSW) (Energy and Petrochemicals Department, Government of Gujarat, 2022).

Grid modernization and interconnection strategies

At the national level, the Green Energy Corridor project was announced to enable dedicated intra and inter-state transmission infrastructure for large solar and wind power projects, starting with eight renewable energy-rich states, including Gujarat (Government of Gujarat, 2024b).

Gujarat's RE Policy (2023) aims to bring about grid enhancement and modernisation to help integrate RE power generation capacity with the existing grid. For the Commercial and Industrial sector, Gujarat RE policy allows promotion of the Green Energy Open Access Regulation 2024 for monthly banking/settlement of surplus RE power with payment of banking charges. The Policy has focused on greening the Power Supply Chain by asking Distribution Companies (DISCOMs) to build consumer preference for shifting to a 100% renewable-based power supply, incentivized through a Green Power Supply Tariff.

Status of Implementation of renewable energy sector in Gujarat:

The state of Gujarat is leading the way for renewable energy transition in India. The state has taken action to implement several measures to overcome barriers and speed up the scale-up of renewable energy, such as

- The Gujarat Energy Development Agency (GEDA) actively sponsors, coordinates and promotes research, policy development, innovation, implementation and collaboration for renewable energy expansion (GEDA, 2025).

- The state launched an integrated renewable energy policy covering major renewable sectors in 2023, which enables a holistic approach to planning renewable energy expansion. The policy covers crucial aspects such as carbon credits, decentralised renewable energy generation, local manufacturing, skill development, employment, investment and innovation. However, it is limited to only wind and solar energy projects (Government of Gujarat, 2023).
- The state and World Economic Forum have proposed the establishment of a Centre for Energy Transition to accelerate energy transition by facilitating public-private sector collaborations on policy, finance and innovation (Times of India, 2024c).
- The state released the Green Energy Open Access regulation in 2024 that can facilitate open access for renewable energy (Government of Gujarat, 2024a).
- The state is launching a dedicated fund to finance renewable energy projects. It also plans to provide support for land identification and acquisition for the projects (Times of India, 2024b).
- The state has mandated nearly 20% renewable purchase obligation for the state DISCOMs for the year 2024-2025, which can help increase market viability for renewable energy projects (Gujarat Electricity Regulatory Commission, 2022). New guidelines which are underway are expected to increase the mandate further.
- The state launched the Akshay Urja Portal in 2024 as one one-stop shop for streamlining and expediting the approval process for renewable energy projects (GUVNL, 2025).
- Gujarat is one of the 10 states where a green energy transmission corridor is proposed by the Union Ministry of New and Renewable Energy (MNRE) to increase the connectivity to new and upcoming renewable energy power plants (Ministry of Power, 2024).
- The Gujarat Energy Transmission Corporation is planning to invest Rs 1 lakh crore to upgrade and expand the transmission infrastructure in the next 10 years to channelize the growth of renewable energy capacity (Times of India, 2024a).
- Gujarat Urja Vikas Nigam Limited (GUVNL) has reserved 16 sites to develop hydro-pump storage stations that can help stabilize the variability of renewable energy (Desh Gujarat, 2024).
- The State has ensured that all state DISCOMS operate profitably and have good financial records, which ensures prompt payments and has boosted investor confidence (Mercom Energy Insights, 2024).
- To diversify the state's renewable energy basket, the state has explored the use of tidal energy in the Gulf of Kutch (Gujarat Power Corporation Limited, 2019) and also launched the waste-to-energy policy in 2022, which can facilitate the expansion of biogas energy (Energy and Petrochemicals Department, 2022, 2024). The recent collaboration between BPCL and Eco Wave Power to explore the untapped potential of wave energy may hold promise for expansion in Gujarat, which boasts nearly 2,400 km of coastline (Press Trust of India, 2025).
- The state government enacted The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act in 2016, which aims to protect landowners and affected individuals during land acquisition process (Government of Gujarat, 2016; Stubb & Kasiva, 2023).
- The Green Energy Transition Research Institute (GETRI), established under GUVNL, offers capacity-building courses to government and non-government personnel. Complementing this, GUVNL has also established the Center for Net-Zero Energy Transition (C-NET) at GETRI—an expert-driven initiative supporting data-informed decision-making, long-term power system planning, and the integration of renewable energy and storage solutions. C-NET strengthens GUVNL's leadership in clean energy through research, innovation, and collaboration, while promoting climate literacy and sustainable practices across its workforce.

To meet the ambitious targets set, the state has introduced measures like streamlined land acquisition, improved grid infrastructure, and financial incentives. To sustain momentum, the state should focus on research and development of technology, market mechanisms and long-term sector sustainability, portfolio diversification and stakeholder empowerment.

5. Power Infrastructure

As of March 2025, Gujarat's total solar PV capacity stands at 17.5 GW1[1], with average annual additions of approximately 3 GW over the past three years. An additional 22 GW of solar PV utility projects are expected to become operational within the next two years (~10 GW annually), bringing the total solar capacity to around 39.5 GW by March 2027[2] (see Figure 5). Out of this 22 GW of Solar PV capacity addition, GUVNL will add 20 GW of Solar PV (which is already tied up till March 2025) and the remaining 2 GW+ capacity will be added by Open Access C&I consumers in the state.

In terms of onshore wind, Gujarat had a capacity of 12.5 GW by March 2025, with average annual additions of approximately 1 GW in the past three years. Around 7.2 GW of new wind projects will be commissioned in the next two years (~3.5 GW annually), increasing total wind capacity to approximately 19.7 GW by March 2027 (see Figure 5). Out of 7.2 GW of Wind capacity addition, GUVNL will add 5.8 GW of Wind capacity (which is already tied up till March 2025) and the remaining 1.4 GW+ capacity will be added by open-access C&I consumers in the state.

Thus, Gujarat's combined solar PV and wind capacity is projected to reach about 59 GW by March 2027. Out of 59 GW, GUVNL will add ~35 GW of Solar PV and Wind capacity by March 2027, and the remaining will be added by Open Access C&I and other state utilities progressively.

In September 2024, Gujarat announced a target of 100 GW of renewable energy by 2030. Assuming that hydro and biomass combined will contribute around 2 GW by 2030, this means an additional 36 GW of solar and wind capacity must be added in the next 2-3 years to meet the 2030 target or approximately 13 GW per year. Figure 5 illustrates the scale of the challenge in terms of capacity addition to reach the target.

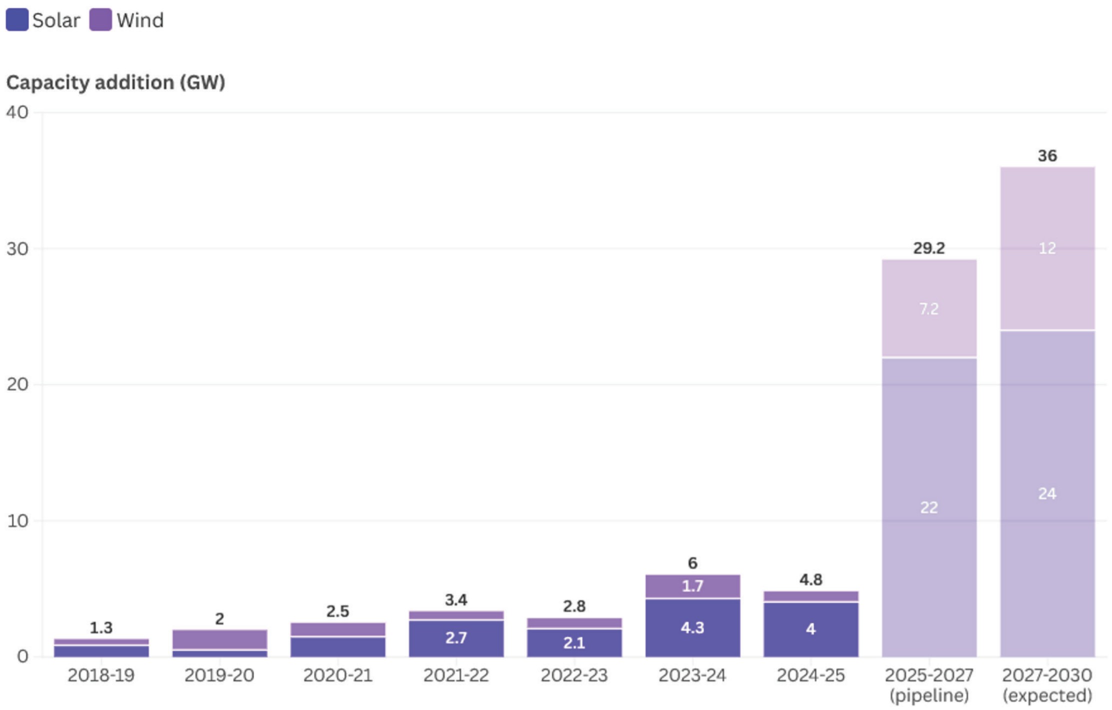

Figure 5: Historical and future capacity additions for solar PV and wind onshore in Gujarat. Historical numbers are until March 2025. Future additions until 2030 are in terms of pipeline and expected capacity in line with the 100 GW RE target by 2030.

Source: Authors' analysis based on data from India Climate and Energy Dashboard. Note: Pipeline and expected installations are not yearly.

[1] https://iced.niti.gov.in/energy/electricity/generation/capacity
[2] https://iced.niti.gov.in/energy/electricity/generation/capacity

Generation infrastructure

According to the modelling results and in line with the ambition to become net-zero by 2070, Gujarat needs to have a cumulative capacity of around 144 GW of solar PV and wind by 2030, with the ratio of solar and wind being 60:40[3]. By 2035, total VRE capacity should increase to 234 GW (See Figure 6).

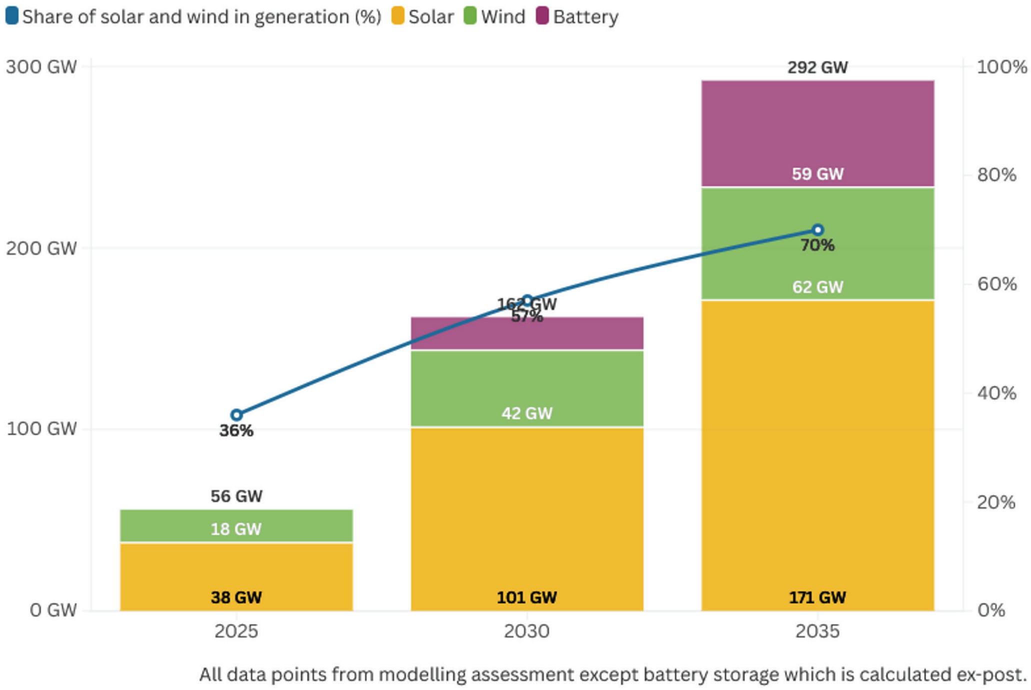

Figure 6: Share of Solar and Wind-based Power, and battery-storage estimation until 2035.

Source:Note all data points are from GCAM analysis results within (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025) except battery storage that is calculated ex-post using information from Table 2.

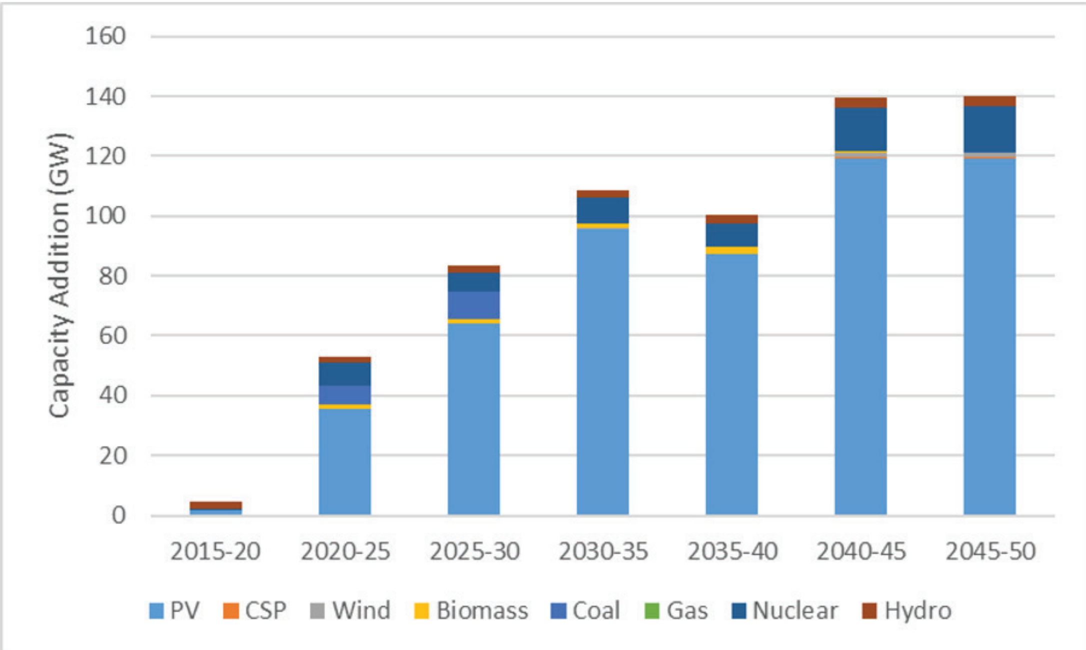

Figure 7: Capacity additions in the short and medium term for Conventional Net Zero scenario (GCAM).

Source: (Global Centre for Environment and Energy (GCEE), Ahmedabad University and Council on Energy, Environment and Water (CEEW), 2025).

[3] Note that the modelling results show the solar and wind requirement to be higher at ~144 GW compared to the 100GW RE target of Gujarat. This is mainly due to higher electricity growth rates assumed in the study as well as higher end-use electrification.

Battery requirement

There is a lack of studies exploring the integration costs and storage requirements for the national grid with different penetrations of solar and wind into the future beyond 2030. Chaturvedi et al., 2018 conclude that under a well-planned system, the utilisation effect from reduced capacity utilisation factor (CUF) of thermal power plants will constitute the dominant share of VRE integration costs up to about 50% penetration. This implies that while costs from transmission and storage will still arise, they are comparatively smaller contributors in this range. However, even with significant declines in storage costs, overall integration costs remain substantial because of the persistence of the utilisation effect. In fact, Deorah et al., 2021 in their study on assessing the requirements of 450 GW RE for India by 2030 mention that "[for a 36% share of VRE] most of the new transmission buildout is driven by the near doubling of electricity demand between 2020 and 2030 [and that] net additional investments in interstate transmission infrastructure for RE integration are found to be small".

Energy storage resources do not generate electricity but enable shifting demand and generation profiles to enhance grid flexibility. Estimating required storage capacities typically involves power system simulations, optimising for periods of surplus generation and unserved demand based on defined load and generation profiles. Additionally, battery storage systems are increasingly deployed to alleviate transmission congestion and provide ancillary services. The demand for grid storage is expected to rise with greater renewable energy (RE) penetration.

A more detailed assessment of demand and generation profiles specific to a region is essential to estimate energy storage requirements accurately. However, this study evaluates battery storage needs by correlating RE generation with varying penetration levels of variable sources, using results from other studies as well as expert judgment. For e.g., Agarwal et al. 2025 assess various pathways for India to meet its 2030 demand. The study captures up to 40% of RE penetration. The study showcases a ratio in storage-to-RE energy requirement of 1:3.5 for an RE mix where solar makes 72% of the RE capacity mix. For higher RE penetration (say 60%), studies show a storage-to-RE energy requirement to be 1:2 (Abhyankar et al., 2023). This trend suggests an exponential rise in storage requirements. However, it is important to recognise that demand-side management, increased interstate capacity sharing, advancements in RE efficiency, and the emergence of new-generation technologies could mitigate the need for extensive grid storage. It should be noted that a more granular approach could yield a higher storage requirement, but meeting the last MW of demand may be economically unviable. Table 2 is used for calculation of battery investment requirements.

Table 2: Share of VRE and its Ratio with respect to BESS.

Share of VRE	Ratio of BESS (KWh)/VRE (KWh)
35 - 40 %	1 : 4
40 - 60 %	1 : 3.5
60 - 65 %	1 : 2
> 65 %	Increases exponentially (back-of-the-envelope calculation not useful)

Source: Authors' analysis.

6. Investment Requirement

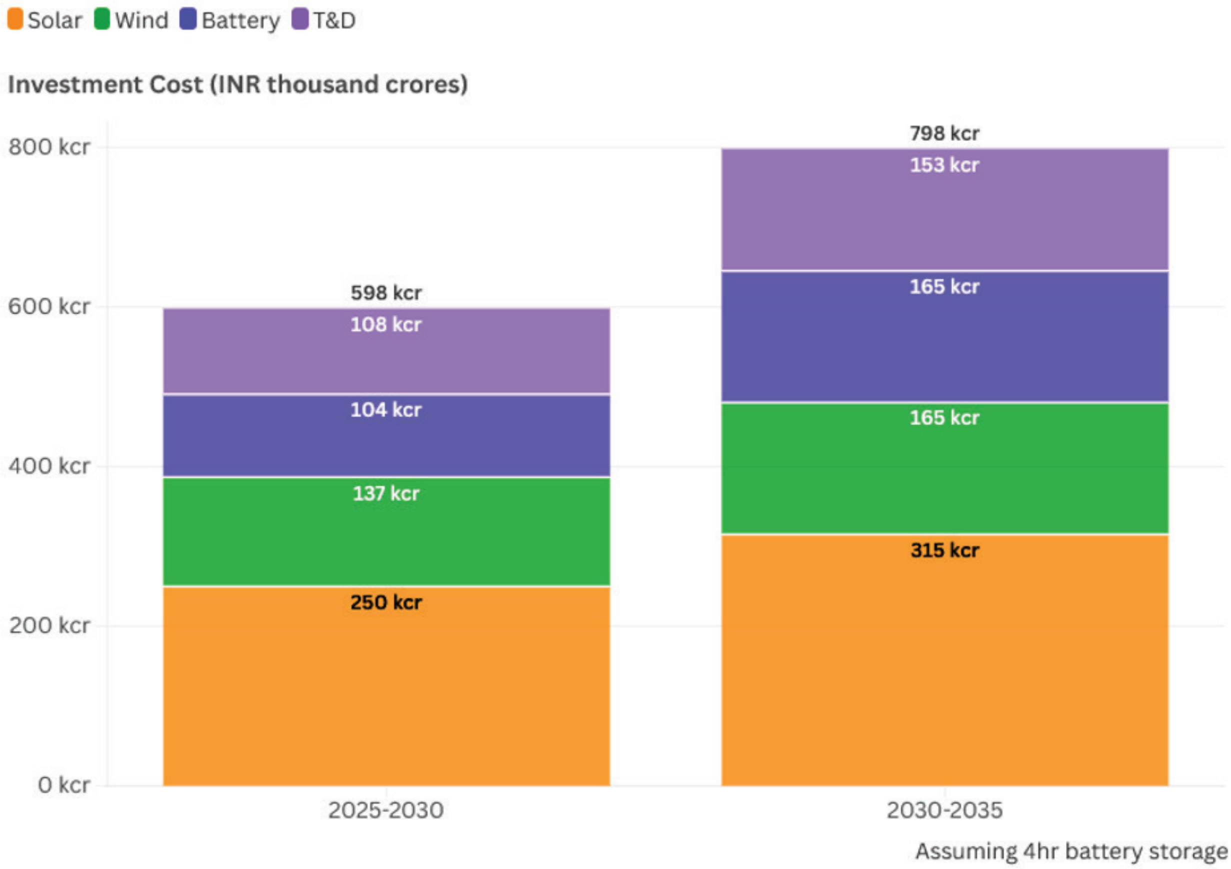

Figure 8: Investment needs in the near-term.

Source: Authors' analysis.

Figure 8 presents investment costs (in thousand crores) for power and related infrastructure based on modeling analysis. Most future investments are driven by solar PV installations, followed by onshore wind. Storage capacity—assumed to come from battery energy storage systems (BESS) and Transmission and Distribution also contributes significantly, bringing total investment to ₹598 thousand crore for 2025-2030 [4].

In 2030-2035, higher solar capacity additions will lead to much higher solar investments. Wind capacity additions are similar to 2025-30. However, battery investments rise substantially due to the growing share of variable renewable energy (VRE) and the corresponding increase in storage needs. Transmission costs per GW of VRE are assumed to remain constant at ₹12.5 million per MW across both periods.

For context, Gujarat's nominal GDP in 2023-24 was approximately ₹25.68 trillion (nominal). Power infrastructure investments alone will amount to ₹1.2 trillion annually—roughly 5% of Gujarat's GSDP. This is an ambitious task, and in Annexure 1, possible sources for financing are provided.

[4] Investment costs for T&D assumed to be 1250 crores/GW

7. Summary

The Assessment of Net Zero Scenarios for Gujarat showed that, achieving the economic growth ambition set under Viksit Gujarat vision for 2047 along with net zero target, the electricity demand is going to increase by 5 times between 2020-2045 to 685.5 TWh. Solar, wind and nuclear combined will constitute 96% of electricity generation in Gujarat by 2045, with 80% coming from solar and wind alone. Cumulatively, the electricity generation in Gujarat will increase by 4 times between 2025 to 2045 to around 1153 TWh. In terms of power generation capacity addition, this would mean by 2045, Gujarat is expected to have 537 GW of power generation capacity with almost 98% of the share coming from renewable energy sources.

Till 2045, Gujarat's direct emissions from electricity generation is expected to grow by 121%, unless the state adopts a Net Zero scenario development pathway, bringing a 70% decrease in direct emission (over the 2020 levels).

Increased electrification coupled with an increasing share of renewables will result in wide-ranging impacts on the economy, environment and society. A significant increase in renewable energy share in the total energy mix in future will enable Gujarat to achieve targets under SDG 7 (Clean Energy) as well as SDG 13 (Climate Action). For the power sector, this could generate new employment opportunities in renewable energy. Our study shows between 3.8 to 6.1 million new green jobs could be generated by 2045 due to RE transition in Gujarat's power sector.

Gujarat is one of the leaders in climate and energy policy development in India, with dedicated policies on increasing the renewable penetration. GEDA and the Climate Change Department, Government of Gujarat are making active efforts to promote renewable energy technologies in the electricity generation sector to ensure fulfilment of developmental aspirations and energy security in the state. There are however several barriers to the successful green transformation of Gujarat's Power Sector. These are listed in Table 3 below along with measures and actions to overcome them.

The Gujarat State Government has made significant progress in scaling up renewable energy generation, demonstrating strong commitment and strategic action. To build on this momentum and ensure long-term sustainability, the following areas require further attention:

1. **Strict Monitoring and Implementation** of current policies to ensure their benefits for scale-up of renewable energy are realised (IRENA, 2018).
2. **Diversifying the energy basket** by integrating coastal and offshore wind, bioenergy, and geothermal energy, supported by a comprehensive integrated policy framework that covers all renewable sources.
3. **Developing market mechanisms** to ensure stable and predictable unit energy costs for developers and create alternative revenue streams for them.
4. **Advancing research and development** in low-cost, long-term storage technologies and improving supply-demand forecasting accuracy and efficiency.
5. **Enhancing operational resilience** through a focused approach on reassessment of renewable energy potential at highly local levels, end-of-life asset management, supply chain resilience, and technology upgradation & standardization.
6. **Expanding vocational training and industry-academia partnerships** to build a specialized workforce and strengthen research capacity (NITI Aayog, 2015).
7. **Improving the land acquisition process** by introducing reforms to increase fairness, transparency, and local acceptance.
8. **Strengthening community engagement** by fostering employment opportunities, enhancing skill development, introducing revenue-sharing mechanisms, and establishing a structured grievance redressal system.

Table 3: Barriers, Measures, Actions Needed and Timeline towards a Net Zero Power Sector.

Barriers	Measures	Actions Needed	Timeline
Resource Constraints (Land availability, Water, social friction)	· Land optimisation through hybrid projects and decentralisation · Increased attention to community compensation and engagement	· Assess opportunities to expand decentralised generation and consumption beyond residential use	Short term
		· Start development of hybrid projects and assess opportunities for co-execution with other sectors such as agriculture	Short term
		· Develop policies to manage water demand for renewable energy projects	Mid term
		· Identify opportunities to increase community involvement in large-scale projects	Short to Mid term
		· Introduce reforms to increase the fairness and transparency of land acquisition process	Mid term
Variability Constraints (Autonomy, Grid Integration, financial risks, climate change)	· Grid management technology advancement · Diversification of energy basket	· Assess the gaps in current grid technology for long-term sustainability	Short term
		· Invest in developing accurate real-time supply-demand forecasting technologies	Short term
		· Increase battery storage, pumped hydro and alternative storage technology systems in the grid	Mid term
		· Increase development and dependence on renewable energy resources other than wind and solar	Long term

Source: Authors' analysis

Barriers	Measures	Actions Needed	Timeline
Financial and Market Barriers (High Costs, Delayed PPAs, Market Risks)	• Unit energy-cost stabilisation and competitiveness • Upfront support for project offtake • Development and integration of other market instruments	• Introduce tax subsidies/ liability to make renewable energy prices competitive	Mid term
		• Implement initiatives to increase the financial stability of state DISCOMs	Short to Mid term
		• Introduce price discovery policies that do not aim for the lowest price	Mid term
		• Introduce green bonds, concessional financing, and risk guarantees for renewable energy projects	Short term
		• Introduce policies to integrate the carbon market and energy certificated into the renewable market ecosystem	Mid to long term
		• Introduce policies to facilitate transparent and reliable open-access market	Short term
Policy & Regulatory Constraints (Misalignment, Short-Term Focus, Cost-Driven Approach)	• Harmonised policies across levels and source • Development of policies with focus on long-term sustainability of the sector • Capacity building at all ranks	• Assessing the current implementation and monitoring status of current policies to increase the efficiency of enforcement	Short term
		• Conduct a policy alignment exercise between central and state governments to identify sources of unnecessary deviation in policies and introduce amendments to reduce them	Short term
		• Introduce integrated policies that cover all renewable sources and effects on aligned sectors such as transportation and cooling	Mid term
		• Initiating research into best practices and innovation for end-of-life management, circularity and lifecycle solutions for renewable energy assets	Short term
		• Introduce policies for proper end-of-life management, circularity and lifecycle solutions for renewable energy assets	Long term
		• Establish a framework for advancing technology R&D	Short term
		• Introduce a structured comprehensive stakeholder consultation process for informing policy	Short term
		• Develop and introduce capacity-building programmes for employees at all levels of decision-making	Short term

Barriers	Measures	Actions Needed	Timeline
Technical Barriers (Storage, Grid Connectivity, Infrastructure Gaps)	• Affordable storage technology and infrastructure • Grid infrastructure upgradation and expansion	• Invest in the development of affordable energy storage systems • Increase government-industry-academia collaboration for storage technology development • Plan for grid upgradation and expansion based on demand forecasts	Short term Long term Short term
Capacity Building & Supply Chain Limitations	• Training and capacity building in the sector • Supply chain resilience in the sector	• Develop technical and vocation skill-building programs • Increase industry-academia collaboration • Assess long-term supply chain vulnerability for the sector • Introduce policies to increase supply chain resilience for the sector	Short term Mid term Short term Long term

Source: Authors' analysis

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Annexure 1 - Financing Options

1. Public Sector Financing

(a) State and Central Government Budgetary Support

- Green Energy Corridor (GEC): Central government funding for transmission infrastructure to integrate large-scale renewables.
- Viability Gap Funding (VGF): Provides upfront capital support for solar and wind projects to make them financially viable.

(b) State-Owned Enterprises (SOEs) and Utility Financing

- GUVNL and GETCO Bonds: These state utilities can issue long-term bonds to raise capital for generation, transmission, and storage investments.
- State-Backed Infrastructure Loans: Gujarat Infrastructure Development Board (GIDB) and Gujarat State Financial Corporation (GSFC) can facilitate low-cost loans for strategic projects.

(c) Green Bonds & Municipal Bonds

- Green Bonds: Issued by the Gujarat government, utilities, or private firms to attract ESG-conscious investors for renewable energy, grid upgrades, and storage.
- Municipal Bonds: Cities with large industrial loads (e.g., Ahmedabad, Surat) could issue bonds to fund urban renewable projects, similar to Pune's municipal bond for solar projects.

(d) Public Private Partnership (PPP)

It can take different forms for RE projects depending on the scale of funding needed, risk sharing mechanism, financing structure and the involvement of government.

- Build-Operate-Transfer (BOT) - Under this contracting model, a private player can build and operate an RE project for a fixed period of time, after which it is transferred back to the government. A variant of this is Build Own-Operate, where there is no transfer to the government.
- Power Purchase Agreement (PPA) - A long-term contract between the government (an electric utility) and the private project developer where there is a long-term contract for the purchase of electricity at a predetermined formula (rate).
- Leasing - Government leases public land to a RE project developer for a fixed period.
- Community based - Local communities (e.g., a milk cooperative) and a private player share financial costs and operational responsibilities

2. Private Sector Investment

(a) Independent Power Producers (IPPs) & Corporate Investments

- PPAs with DISCOMs & Corporate Buyers: Gujarat's industries can sign long-term Power Purchase Agreements (PPAs) with solar and wind developers, reducing reliance on state funding.
- Open Access & Captive Power Projects: Large industrial consumers (e.g., Adani, Reliance, Tata) can invest in private renewable projects for cost savings.

(b) Infrastructure Investment Trusts (InvITs) & REITs

- Renewable InvITs: Publicly traded investment vehicles pooling capital from investors for solar/wind/storage assets (e.g., KKR-backed Virescent, IndiGrid).
- Real Estate Investment Trusts (REITs) for Solar Rooftops: Investors finance rooftop solar on commercial buildings, leasing the assets for revenue.

(c) Corporate ESG & Sustainability-Linked Financing

- Sustainability-Linked Loans (SLLs): Companies can secure loans with interest rates linked to ESG performance (e.g., decarbonization targets).
- Green Corporate Bonds: Issued by industrial giants (e.g., Tata Power, ReNew) to fund renewable energy projects in Gujarat.

3. International & Development Finance

(a) Multilateral & Bilateral Loans

- World Bank & ADB Loans: Gujarat can seek concessional financing for grid modernization, battery storage, and transmission.
- AIIB & NDB (BRICS Bank) Loans: Funding support for solar, wind, and transmission infrastructure.
- Bilateral Climate Finance: Grants and concessional loans from Germany (KfW), France (AfD), Sweden (SIDA), Denmark (DANIDA), Japan (JICA), and the US (DFC) for renewable projects.

(b) Climate Finance & Export Credit Agencies (ECAs)

- Green Climate Fund (GCF) Grants: Can support Gujarat's large-scale storage and transmission investments.
- Export Credit Agencies (ECAs): Financing from agencies like JBIC (Japan) and US EXIM Bank for technology imports (e.g., battery storage, grid management software).
- Special Climate Funds: Climate Investment Fund (CIF) has invested around USD 793 million in the energy sector in India. REEEP is another fund focussed on renewable energy and can be a potential source of funding for small-scale projects
- Article 6 : Article 6 of the Paris Agreement provides a framework for countries to cooperate towards the implementation of their Nationally Determined Contributions (NDCs) through carbon markets (Articles 6.2 and 6.4) and non-market modalities (Article 6.8).

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