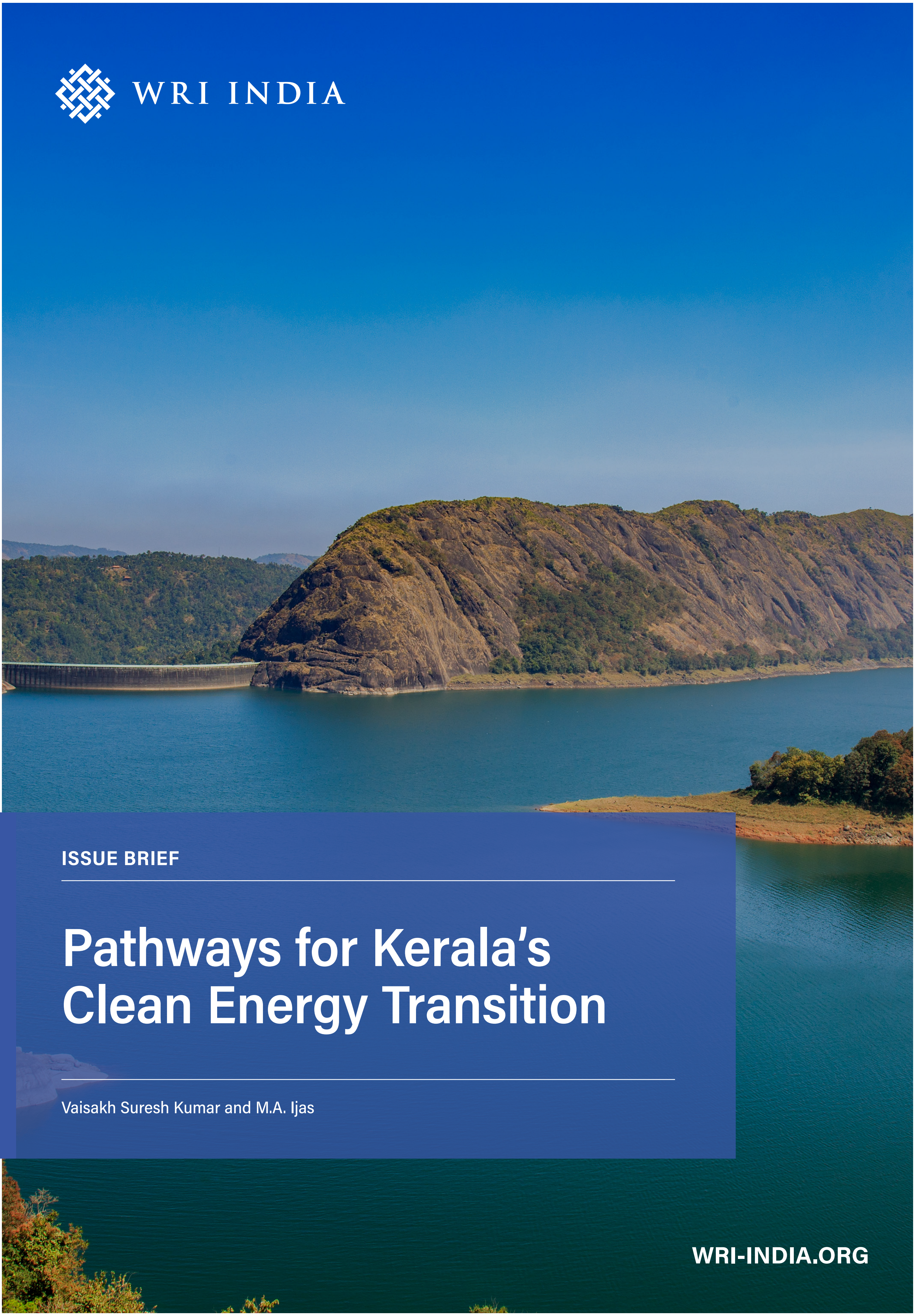

WRI INDIA

ISSUE BRIEF

Pathways for Kerala's Clean Energy Transition

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CONTENTS

Issue briefs focus on policy issues and clearly draw out the implications of existing evidence for decision makers.

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HIGHLIGHTS

- Although Kerala aspires to become a 100 percent renewable energy (RE)-based state by 2040 and carbon neutral by 2050, as of fiscal year 2025 (FY2024–25), around 60 percent of the consumed electricity was sourced from thermal power plants located in other states. By contrast, the share of RE (wind, solar, and small hydro) stood at 7 percent, with large hydro and nuclear contributing the remaining share.
- It is necessary to analyze the pathways the state can explore while planning its RE targets and assess whether the current pace of capacity additions is sufficient for meeting them.
- This issue brief uses a scenario-building approach to study Kerala's electricity supply and demand projections under varying assumptions.
- Under the Business-as-usual (BAU) scenario (i.e., the baseline scenario, with future capacity addition based on current policy targets and historical trends), Kerala can meet its electricity demand for 2030 from available sources. However, shortfalls in electricity generation are expected to occur post 2035.
- Other scenarios that consider accelerated capacity additions of wind and solar, along with thermal capacity reductions, also result in a thermal share of about 30 percent by 2040.
- Transitioning completely to renewables by 2040 will be challenging, considering Kerala's renewable landscape and the financial requirements.

Executive summary

Context

India has set ambitious renewable energy (RE) targets, and support from individual states is key to a successful transition. In line with the overall sustainability targets of the country and to meet its growing electricity demand while reducing dependence on imports, Kerala has formulated an ambitious energy transition agenda: achievement of 100 percent RE by 2040 and carbon neutrality by 2050. However, the implications of this transition and the measures proposed to achieve it are neither widely explored nor communicated in the policy discourse of the state. For example, there are limited studies on the magnitude of renewable capacity additions required to transition to 100 percent RE by 2040 to address the growing electricity needs of the state. Additionally, there is limited information on the financial resources needed to support this transition. This is a critical gap because interventions to facilitate the energy transition will impact long-term electricity planning for the state.

About this issue brief

The objective of this issue brief is to inform various stakeholders (the Power Department, the State Planning Board board [SPB], the Kerala State Electricity Board [KSEB], the Agency for New and Renewable Energy Research and Technology [ANERT], and the Energy Management Centre [EMC]) about the possible energy transition pathways for the state and their implications for the state power sector and to identify long-term electricity planning priorities. The paper also explores whether the current pace of capacity additions and the renewable targets outlined in state policies and capital investment plans are in line with the state's 100 percent renewable ambitions. Additionally, the paper provides information on the current source-wise electricity mix along with the source-wise share of domestic generation, electricity imports, and current and future electricity supply and demand projections for different scenarios, along with financial considerations. This information can inform policy and decision-making to ensure that the state's long-term electricity planning is in line with the proposed targets.

Four scenarios are considered: a Business-as-usual (BAU) scenario, a High Renewables scenario, a scenario in which thermal power purchase agreements (PPAs) are not renewed, and an exploratory scenario that examines the interventions needed to move away completely from thermal sources by 2040.

Key findings

- Kerala currently imports nearly 70 percent of its electricity, mostly from thermal power plants. The supply of electricity is from state-utility-owned generating stations, power purchases from central generating stations, and open access contracts with private suppliers located outside the state.
- Despite the lack of thermal power plants in Kerala, the share of thermal sources in the electricity mix is high. The renewable share is currently only about 7 percent. The state aims to significantly increase its renewable share, aiming to transition completely to RE by 2040.
- To understand the diverse pathways Kerala can consider, we modeled four scenarios, along with sub-scenarios, to understand the state's electricity supply-demand characteristics up to 2040. The scenarios considered include a BAU scenario, a High Renewables scenario, a scenario in which thermal PPAs are not renewed, and an exploratory scenario that examines the interventions needed to move away completely from thermal sources by 2040. These scenarios are described in the section titled "Scenario description."
- Under the BAU scenario, Kerala's electricity demand is estimated at 35,668 and 56,057 million units (MU) for 2030 and 2040, respectively. Under this scenario, the state can meet its demand for 2030 by using the available energy generation sources. However, excess generation decreases beyond this year, and shortfalls in meeting the electricity demand occur post 2035. The share of electricity from thermal sources is 52 percent in 2030 and about 37 percent in 2040. The renewable share in the energy mix (wind + solar) would be around 15 percent for both 2030 and 2040. It is observed that Kerala would not be able to meet its 2040 renewable targets under this scenario.
- Additionally, we find a shortfall in electricity generation relative to demand after 2035 under the BAU scenario. Although accelerated additions of solar and wind can help offset the shortfalls in energy generation, the share of thermal sources in the 2040 electricity mix remains high.
- In the High Renewables scenario, accelerated capacity additions of solar and wind help offset the shortfalls in electricity generation faced under the BAU scenario beyond 2035. In this scenario, solar capacity additions of about 700 megawatts per year (MW/year) are modeled along with wind capacity additions of 115 MW by 2030, increasing to 1,115 MW by 2040, utilizing Kerala's available solar and wind potential. Under this scenario, renewable (wind + solar) generation increases to 26 percent. However, the thermal share is still 37 percent in 2040.

- In the Low Thermal (Nonrenewal of Expiring Thermal PPAs) scenario, expiring PPAs with thermal power plants are not renewed, aiming to reduce dependence on thermal power. However, this leads to a significant electricity shortfall by 2034, which is earlier than in the BAU scenario. High solar and wind capacity additions, along with other renewable or green energy open access (OA) capacity additions, could be considered to improve the overall generation and meet the demand. This improves the contribution from renewable generation to 48 percent by 2040 while mostly meeting the electricity demand. However, the share of thermal remains high, at about 29 percent, in 2040.
- We find that for all of the above scenarios, Kerala's share of thermal electricity remains high by 2040, which is not in line with the state's target of 100 percent RE by 2040. Hence, it is likely that nonrenewable sources will still contribute to Kerala's electricity mix in 2040. However, it will still be interesting to understand what likely RE capacity additions would be required for Kerala to reduce its share of thermal electricity to zero.
- The Zero Thermal 2040 scenario is an exploratory scenario that examines the interventions required for Kerala to completely eliminate thermal electricity by 2040. In this scenario, thermal capacity is gradually reduced to zero by 2040. It is observed that without intervention to compensate for the reduction in thermal capacity, the state would experience shortfalls in meeting the electricity demand by 2027. This is because in this scenario, thermal capacity, which forms the base supply, is reduced. To meet the demand, capacity additions of wind, solar, and hydro power plants within Kerala along with RE electricity procurement from other states through PPAs and OA agreements are considered.
- In the Zero Thermal 2040 scenario, significant renewable capacity addition—of approximately at least 16 gigawatts (GW) in addition to the wind and solar capacity additions available within the state—will be required to compensate for the reduction in thermal capacity. Overall, it is observed that at least 27 GW of renewable capacity addition is required to meet the demand in 2040 purely from renewables, hydro, and nuclear without any thermal support.
- The investments required to enable the energy transition are also computed: an investment of INR 64,890 crore would be required for all the capacity additions.

Recommendations

- To achieve Kerala's renewable targets, the current pace of RE capacity additions would need to significantly increase. In addition to harnessing the available renewable potential within the state (from solar, wind, wave energy, and bioenergy), long-term OA contracts from RE installations in other states should also be explored. Additionally, existing thermal capacity would need to be replaced by renewable or green energy OA contracts, along with mechanisms to manage peak demand, the variable nature of renewables, and grid stability. Overall, Kerala needs to be more proactive in utilizing all available resources to achieve its energy transition goals.
- Considering the limited renewable resources available within Kerala (10.9 GW solar, 2.3 GW wind, 4.9 GW wave energy, 0.7 GW of bioenergy, 0.65 GW small hydro, etc.; see Appendix C), it can be inferred that these alone cannot help the state fully address the energy demand and renewable targets going forward. Kerala could also explore investing in other states for setting up wind, solar, and other renewable installations and bring the generated power into the state.
- The state would likely need around 27 GW of RE capacity to completely transition from thermal dependence. To achieve higher renewable capacities, Kerala could explore all of the above options. These RE capacity additions would need to be complemented with energy storage technologies; however, we have not modeled these, which is a limitation of this study.
- Considering the slow pace of installations of large wind turbines, Kerala could explore the use of smaller-capacity large wind turbines for projects and small wind turbines in a decentralized RE generation mode, to augment capacity and harness more of the available wind resources.
- To harness the available solar potential in the state, Kerala needs to consider utility-scale solar installations to the extent possible (utilizing land available with government companies), further increasing the installation of floating solar and decentralized options, such as rooftop solar.
- The combined effort of tapping into Kerala's available potential to the extent possible, establishing PPAs and contracts with renewable installations outside the state, setting up renewable projects outside the state and wheeling power, and exploring new renewable technologies such as wave energy is essential for the state to achieve its targets. Additionally, going forward, purchasing power from renewables may be cheaper than purchasing thermal power. However, this will be

challenging considering the financial requirements and scale of capacity additions required. Hence, it is highly likely that thermal and nuclear contributions will persist in Kerala's energy mix in 2040.

- It may be noted that during 2015–25, the state added nearly 2,000 MW of RE to the electricity grid. Over 90 percent of this capacity came from domestic consumers through rooftop solar photovoltaic (RTS-PV) installations. With the exhaustion of low-hanging fruit and the introduction of regulatory barriers, further growth can be achieved by promoting newly opened market modes. Mechanisms such as group net metering, captive or group captive generation, behind the meter systems, and peer-to-peer trading could be explored in this regard. Adoption of such RE installations can relieve the financial burden of future investments in the sector.
- In addition to Kerala's budgetary allocations, the transition to 100 percent RE will likely need the mobilization of private and international finance. Public-private ventures and investments in areas such as floating solar, community battery energy storage systems (BESS), and green hydrogen could also be explored to facilitate this initiative.
- It is also important that the distribution utility's Resource Adequacy (RA) plan and LTDRAP (Long Term Discoms Resource Adequacy Plan) align with energy requirements for meeting the electricity demand reliably and affordably. Further grid enhancements, including energy storage, are also essential for absorbing the electricity generated (we have not directly modeled energy storage in this study).
- In regard to the above point, larger private participation in the distribution sector is essential, along with strengthened consumer participation in Kerala's energy governance. Kerala could also involve research institutes and colleges within the state, such as Cochin University of Science and Technology (CUSAT), Indian Institute of Technology (IIT) Palakkad, and Indian Institute of Management (IIM) Kozhikode, to chart periodic reviews of sectoral studies. Such studies could include new technologies, policy advisories, business models, and so on.

Note: The numbering system followed in this issue brief is the Indian numbering system. Typical values used are lakh (1 lakh = 100,000) and crore (1 crore = 10 million).

Introduction

Rationale for the study

Kerala aspires to become a 100 percent renewable energy (RE)-based state by 2040 and carbon neutral by 2050.[1] Currently, about 54-66 percent of the electricity consumed in the state is from thermal sources, while the share of renewable sources is about 5 percent. Hydro and nuclear contribute the remaining shares (KSEB 2025b). A study by Centre for Science Technology Energy Policy (CSTEP) (CSTEP 2024) explores two pathways for the greater adoption of renewables in Kerala. In both these pathways, the share of renewable generation is projected to be less than 50 percent in 2040. In both these pathways, thermal sources also contribute to the energy mix in 2040. Further, the report on the Resource Adequacy (RA) plan for Kerala by Central Electricity Authority (CEA) noted that the state would need to contract additional coal-based capacities in future years. Hence, it is necessary to analyze the pathways Kerala can explore to meet its 2040 100 percent RE target. It is also necessary to understand whether or not Kerala's current pace of capacity additions and its policy targets are adequate to achieve its renewable ambitions and implement the interventions required to help it transition to a clean energy future. Notably, Kerala currently imports nearly 70 percent of its electricity, mostly from thermal power plants, the scaling down of which could have major resource planning implications.

However, the implications of this transition and the measures proposed to achieve it are not widely explored and communicated in Kerala's policy discourse. For example, the magnitude of renewable capacity additions required to transition to 100 percent RE by 2040 in order to address the growing electricity needs of the state is not well documented. This is a critical gap because the energy transition will have a decisive impact on Kerala's long-term electricity planning.

The objective of this issue brief is to inform stakeholders (the Power Department, the State Planning Board [SPB], the Kerala State Electricity Board [KSEB], the Agency for New and Renewable Energy Research and Technology [ANERT], and the Energy Management Centre [EMC]) about Kerala's various energy transition pathways and their implications for its power sector and to identify long-term electricity planning priorities. The paper also explores whether or not the current pace of capacity additions and renewable targets outlined in state policies and capital investment plans is in line with the state's 100 percent RE ambitions. The brief also provides information on Kerala's current source-wise electricity mix, the source-wise share of electricity generated, and electricity imports; current and future electricity demand; and electricity generation (supply-demand) characteristics for various scenarios. This information can inform policymaking and decision-making.

This issue brief complements the broader efforts being undertaken in Kerala to support its energy transition, This issue brief including in-depth technology assessment (Kumar et al. (2025). The authors of this working paper examine various renewable and supporting technologies for Kerala's energy transition. This issue brief builds on the information provided by Kumar et al. (2025) by analyzing various scenarios for the energy transition and describing their implications.

Literature review

Scenario-based power sector modeling is an essential step in long-term capacity addition planning. It is a useful exercise at both the national and state levels. Energy modeling tools such as the Low Emission Analysis Platform (LEAP) are widely used for performing scenario-based analysis, long-term capacity planning, and energy accounting. LEAP is an example of a bottom-up model used to track energy consumption, generation, and resource extraction for national and subnational energy systems. The tool was developed by the Stockholm Energy Institute (SEI) for energy policy analysis and climate change mitigation assessment, with wide application in 200 countries and territories (Heaps 2026). The tool helps map state-level electricity supply and demand projections and their impact on greenhouse gas (GHG) emissions levels.

Although studies that apply LEAP to model Kerala's power sector are limited, similar studies have been carried out for other states, such as Tamil Nadu. For example, Sundararagavan et al. (2022) outlined various low-carbon pathways that Tamil Nadu can consider for its energy transition, showcasing the supply-demand characteristics and emission profiles for each pathway. The paper also provides insights into how integrating energy planning exercises can help state-level planners, policymakers, and utilities set policy targets and design long-term clean energy pathways. The paper is useful for this study because it provides information on the use of the LEAP tool for power sector planning. The paper also provides information on the methodology followed for building the model along with the various parameters that need to be considered. It also validates the use of LEAP for power sector modeling at a subnational level. Although the overall methodology can be replicated for Kerala, the findings and recommendations discussed in the paper are applicable to Tamil Nadu alone.

CSTEP (2024) presents a detailed analysis of Kerala's energy sector and provides a roadmap outlining the initiatives, policies, and measures that can guide the state in moving toward a smooth energy transition. The paper gives a useful overview of Kerala's power sector. It examines two scenarios—a baseline Business-as-usual (BAU) scenario and a High Renewables scenario—to analyze the energy transition and helps understand the various parameters considered under the High Renewables scenario. In addition, it is useful for verifying some of the assumptions and results obtained from the current study. However, we find that in both the scenarios considered in CSTEP (2024), the renewable share in 2040 is less than 50 percent, which does not meet the state's target of 100 percent RE by 2040. Additionally, we find that the state's long-term power purchase agreements (PPAs) and their nonrenewal—which can further help reduce the share of thermal power and reduce power purchase costs—are not considered in the scenarios. It is also necessary to understand the likely costs associated with each scenario or pathway because it is a key aspect of decision-making; however, this aspect too is not outlined in the paper. Hence, it is necessary to examine more pathways or scenarios for Kerala's energy transition that could help the state achieve its target of 100 percent RE by 2040 and assess the investment required for the infrastructure.

Fernandes and Sharma (2023) examine the likely savings realized if the existing thermal Open Access (OA) agreements were replaced with renewable purchases. This paper is useful because it provides information on Kerala's existing long-term and medium-term OA arrangements with various central and private thermal power stations. The authors provide information on the remaining term of active PPAs, the pricing associated with each PPA, and the likely savings the state could realize if it completely shifted to RE. However, they do not offer details regarding the electricity mix required to meet demand following the termination of the existing PPAs. They also do not consider multiple demand-supply scenarios and the costs associated with each scenario.

It is also important to understand Kerala's RE potential, the current installed capacity, and the challenges that hinder capacity expansion. This information can help develop scenarios in which renewable technologies are selected carefully and capacity additions are considered realistically. Kumar et al. (2025) explore these aspects in detail and use a technology assessment framework (TAF) to identify renewable technologies suitable for Kerala, providing information on the available potential, the current installed capacity, and challenges to the adoption of these technologies. Appendix C summarizes the key insights from the paper that informed our study.

The literature, as discussed above, does not prioritize Kerala's renewable capacity and its composition, the energy mix, and the likely costs of the energy transition. Therefore, this issue brief addresses this information gap through scenario modeling of current and future electricity demand; demand and supply characteristics considering current capacity addition trajectories based on existing plans and policies; capacity additions required to meet the 2040 target of 100 percent RE; the costs of these capacity additions; and the supply-demand characteristics across various renewable capacity addition scenarios.

A snapshot of Kerala's electricity landscape

Kerala imports more than 70 percent of its electricity, mostly from thermal power plants. The remaning is generated within the state by KSEB, independent power producers (IPPs), captive power producers (CPPs), and co-generation and solar prosumers.

Kerala's total electricity supply was 33,606 Million Units (MU) in 2024–25 (KSEB 2025b). Table 1 provides an overview of the percentage share of the supply through various power procurement methods. Around 85 percent of Kerala's electricity supply is obtained from hydro located within the state; thermal, and nuclear central generating stations (CGSs) located outside the state; long-term open access (LTOA) contracts from private power plants; and power purchases through power exchanges. Internal thermal generation (from power plants within the state) is negligible, but the share of thermal from CGS, LTOA, and medium-term open access (MTOA) is high, as shown in Figure 1. The contribution of various sources to Kerala's electricity supply is as follows: 54 percent for thermal, 20 percent for large hydro, 8 percent for nuclear, 7 percent for renewables (solar, wind, and small hydro), and the remaining from power exchange purchases, deviation settlement mechanisms, and SWAP.

Figure 2 shows Kerala's electricity supply from FY2015–16 to FY2024–25. Over this 10-year period, KSEB's internal generation increased from 6,739 MU to 7,320 MU. During FY2021–22, internal generation was 9,673 MU, mainly due to favorable conditions, water availability, and minimal plant shutdowns. Generation by private power producers (IPPs and CPPs) and prosumers also increased from 278 MU to 1,591 MU; this generation was predominantly from RE sources, including small hydro, wind, and solar. Power purchases from external sources (CGS, LTOA, MTOA, and power exchanges) also increased to the tune of 15,639 MU in FY2015–16 and 27,532 MU in FY2024–25. The slight decrease in external

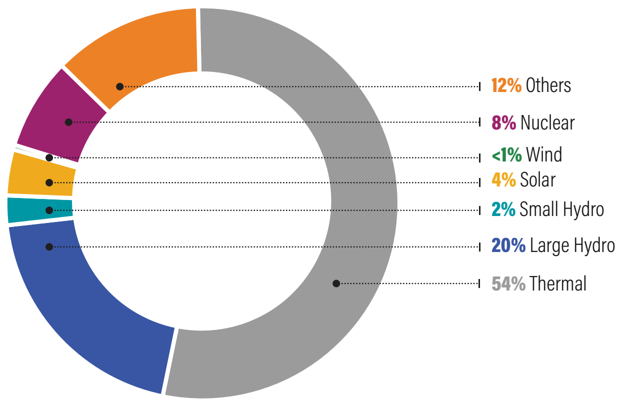
Table 1 | **Distribution of power procurement methods by percentage share**

KSEB'S INTERNAL GENERATION	SHARE (%)
Hydro	21.64
Wind	<1
Solar	<1
Thermal and Diesel	<1
POWER PURCHASES	
IPPs, CPPs, co-generation, and prosumers	4.73
CGS	34.41
LTOA	19.79
MTOA and STOA	6.97
Power purchase through power exchanges	8.68
SWAP return	2.32
Unscheduled import and deviation settlement	1.29

Note: CGS = central generating station. CPP = captive power producer. IPP = independent power producer. LTOA = long-term open access. MTOA = medium-term open access. STOA = short-term open access. SWAP refers to the exchange of electricity between utilities or states to manage seasonal or temporal variations in supply and demand.

Source: KSEB (2025b) and authors' analysis.

Figure 1 | **Sources of electricity supply (2024–25)**



Note: Others are purchases from power exchanges, deviation settlement mechanisms and SWAP. This supply may also be of thermal origin.

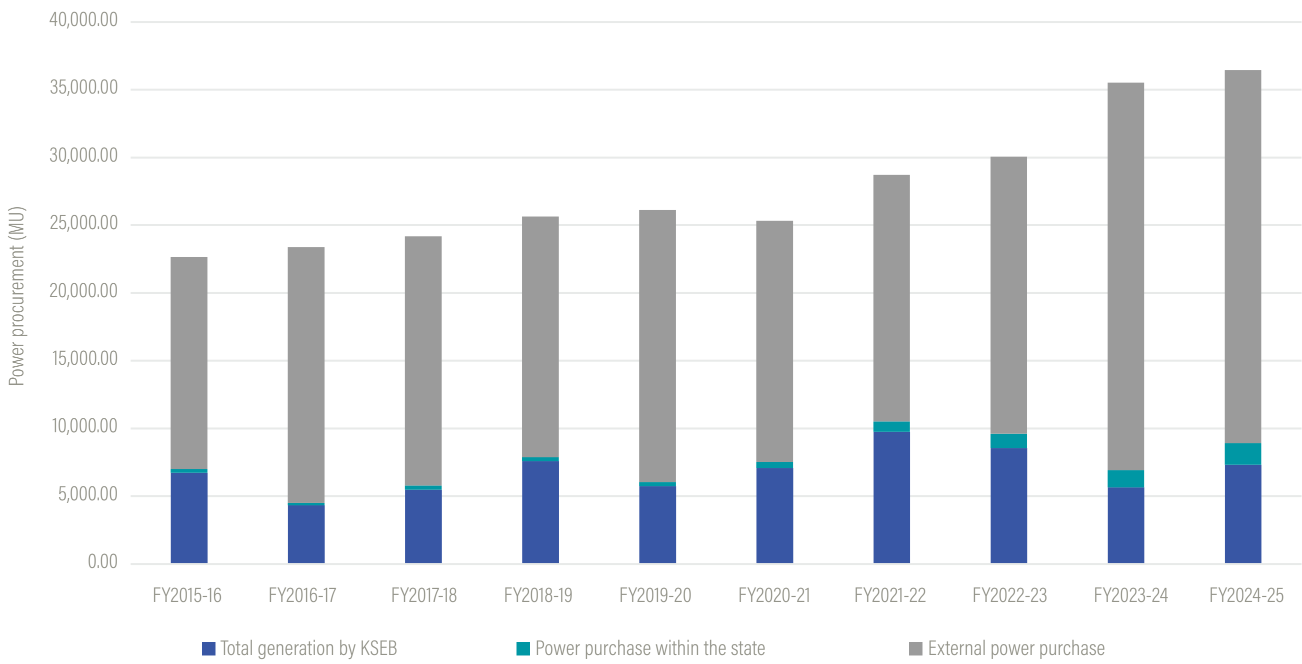
Source: KSEB (2025b) and the authors' analysis.

power purchases over the last two years was offset by a modest increase in internal generation.

Figure 3 shows the available proportions of various electricity sources in Kerala's annual electricity supply over a 10-year time frame. As of FY2024–25, the state's total installed capacity was 4,412 megawatts (MW). The total capacity, including power allocations from external power plants through PPAs, was 7,342 MW (short term capacity allocations not included). The contributions of various sources to the installed capacity include 42 percent for thermal, 31 percent for hydro, 5 percent for nuclear, 21 percent for solar, and 1 percent for wind. The capacity addition trends for 10 years are 8 percent annual growth for wind, 1 percent annual growth for hydro, 3 percent decline for thermal, and 9 percent annual growth for CGS+LTOA. Solar has grown at an annual growth rate of 83 percent since FY2016–17. Figure 4 gives the installed capacity of various renewable sources in Kerala.

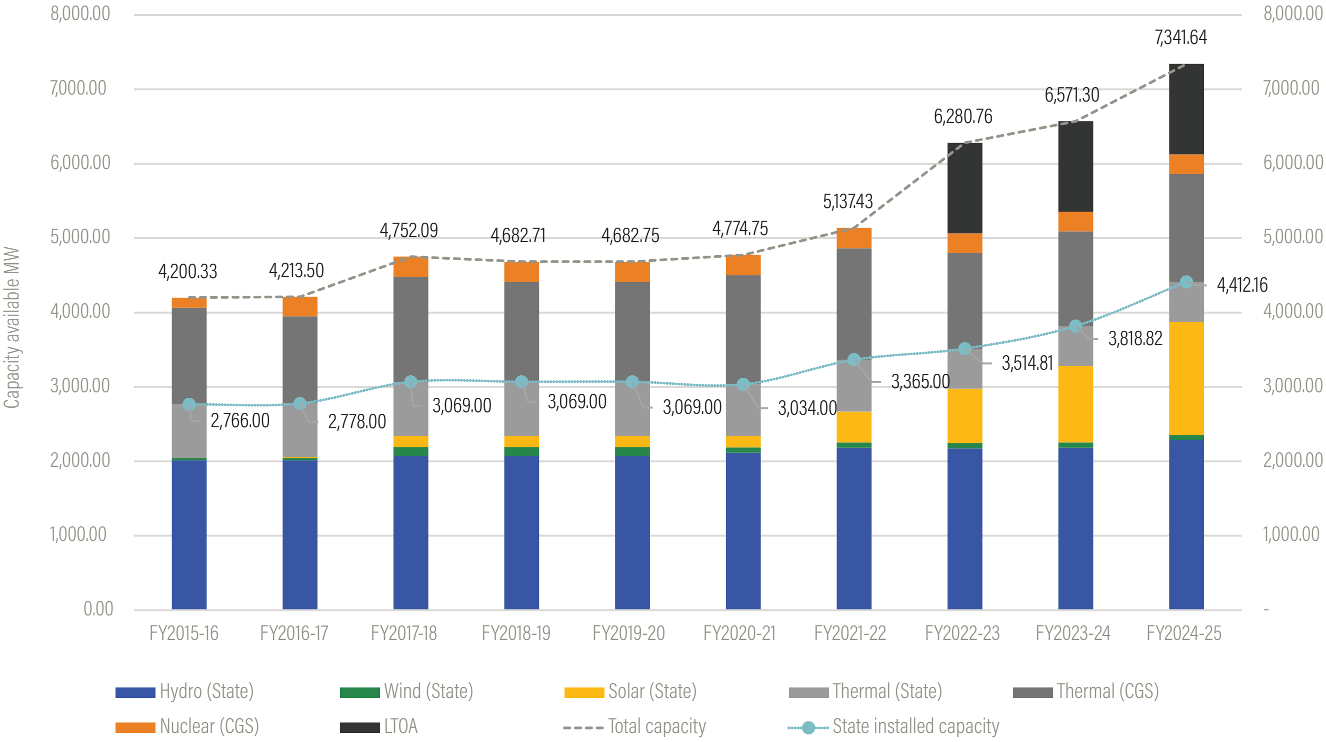
Kerala's electricity demand has been growing at a compound annual growth rate (CAGR) of about 4.4 percent annually over a 10-year period, from FY2015–16

Figure 2 | **Kerala's electricity supply mix**



Note: FY = fiscal year. KSEB = Kerala State Electricity Board. MU = million units.
Source: KSEB 2025b.

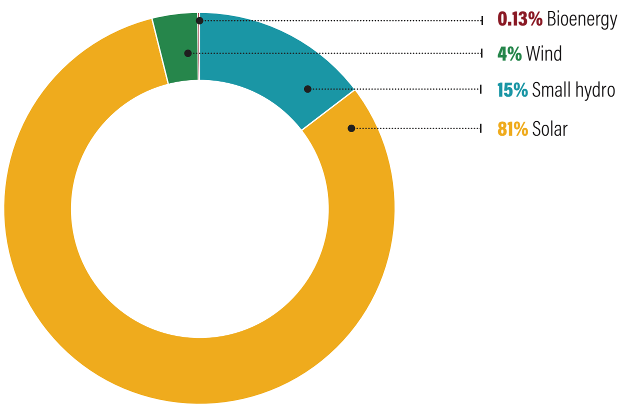
Figure 3 | Kerala's source-wise electricity supply mix



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. Information on LTOA contracts are provided based on available data. MTOA and STOA capacities are not included.

Source: KSEB (2025b) and the authors' analysis.

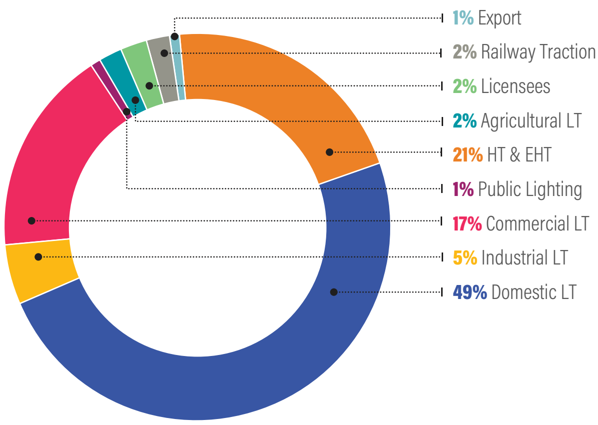
Figure 4 | Kerala's installed renewable energy capacity as of March 2025



Note: KSEB = Kerala State Electricity Corporation. MW = megawatt. SHP = small hydro power. According to the renewable energy (RE) statistics for 2024–25, Kerala's installed RE capacity as of March 2025 was 1,889.23 MW (1,538.94 MW solar, 2,76.52 MW SHP, 71.27 MW wind, and 2.5 MW bioenergy). Bioenergy is absent in the KSEB's power system statistics.

Source: MNRE 2025.

Figure 5 | Category-wise energy sales (MU), FY2024–25



Note: EHT = Extra High Tension. FY = fiscal year. HT = High Tension. LT = Low Tension. MU = million units.

Source: KSEB (2025b) and the authors' analysis.

(KSEB 2025b). Figure 5 shows the category-wise energy sales in million units for FY2024–25. The highest demand arises from the Domestic category, followed by the High Tension and Extra High Tension (HT & EHT) and the Commercial Low Tension (LT) categories.

Scope, research questions, methodology, and limitations

Kerala has set ambitious renewable targets; however, the interventions required to achieve these targets are not outlined in the state's policies and planning. This information, if available, can help the state government better plan renewable capacity additions. It can also help the state government approach the targets in a more realistic and informed manner, considering factors such as electricity demand, available RE potential, and costs. It can also help stakeholders visualize changes in the electricity mix over the years up to 2040.

This is important because Kerala needs energy planning to avoid power shortages and decrease dependence on costly imports. Energy planning can also help set the right balance among various electricity-generating sources, plan for storage, and estimate the cost and the investment required.

Research questions

- Kerala has set a target of 100 percent RE by 2040. What pathways can it consider for achieving this?
- Is the current pace of renewable capacity additions and interventions in line with Kerala's targets and vision for 100 percent renewables by 2040?
- What will be the financial implications of and the investments required for the distinct pathways that Kerala can consider?

Methodology

This study utilizes LEAP, a software tool for energy policy analysis developed by SEI, to conduct scenario-based modeling to map out state-level electricity supply and demand projections. The process flow for LEAP computation involves developing a problem statement and boundary conditions for the modeling exercise, followed by identifying publicly available data sources for supply and demand, supplemented by stakeholder discussions. The collected data are cleaned and compiled. Various scenarios are developed and the results compared.

The results will be analyzed to understand the future power sector requirements under various supply-demand scenarios, such as renewable capacity additions, cost requirements, thermal PPAs that need to be discontinued, and likely renewable or green energy open access (OA) contracts required. We also analyzed the financial implications for each scenario, taking into account projected future power purchase costs. See Appendix A for the analysis and results.

The data for building the scenario-based model are derived from a review of the policy and regulatory literature. This includes Kerala's policy documents, tariff order documents, state load dispatch center's reports, southern regional load dispatch centers' reports, the utility's capital investment plans, KSEB's power system statistics report for historical data, category-wise energy demand and supply source-wise information, and future capacity additions (KSEB 2023, 2024, 2025b; SRLDC n.d.). Our review also includes reports published by state departments and central government agencies to understand the state's overall renewable potential and renewable capacity addition plans. The literature review is complemented by inputs from stakeholder discussions and convenings. Considering all of the above, we developed relevant scenarios for the model.

The capital investment potential to add new RE power plants—whether by KSEB or private developers—to meet the required internal RE generation, the cost of procuring electricity from these sources, the cost savings from the abatement of thermal electricity, and procurement involving discontinuation of thermal PPAs to achieve RE goals are also analyzed for each scenario. The investments required for KSEB's existing plans to implement hydroelectric power plants are also incorporated in this analysis. For this, we analyzed the changes in electricity procurement costs from various sources since 2018 and KSEB's projections, including the Kerala State Electricity Regulatory Commission (KSERC) tariff orders 2018–2023 and 2022–2027, National Electricity Plan 2022–32, and so on. Appendix A details the methodology followed for the financial calculations.

Limitations

The demand projections for this study were made using historical data, validated through comparison with projections by CEA and KSEB. However, a limitation of using historical data for bottom-up demand projection by consumer category is that such data cannot fully capture future trends in consumption levels or their temporal patterns. Hence, the current analysis may not accurately account for emerging shifts and the associated demand patterns.

Further, the current analysis presents a macro and long-term snapshot of Kerala's power sector. We have not explored short-term requirements and fluctuations and their mitigation. The current modeling study also does not consider hourly dispatch. Thus, we have not considered energy storage aspects in this computational exercise. Other studies estimate storage requirements between 3.8 gigawatts (GW) and 4.1 GW for managing peak demand and enhancing grid flexibility (CSTEP 2024).

We have also not considered spot market volatility, hedging strategies, short-term contracts, and the associated cost impacts. Further, greater reliance on RE will necessitate smart grid upgrades and dynamic energy management mechanisms to avoid supply gaps during peak demand or low-RE generation periods. Kerala´s unique consumption pattern of consuming electricity predominantly during non-solar hours is also not considered in this issue brief.

For the financial analysis presented in this issue brief, we compute the capital costs for capacity additions and the associated savings, if any. The operational costs are not considered, and this is another limitation of the study. The investment required for the development of transmission and distribution (T&D) infrastructure and storage facilities to manage demand is not included.

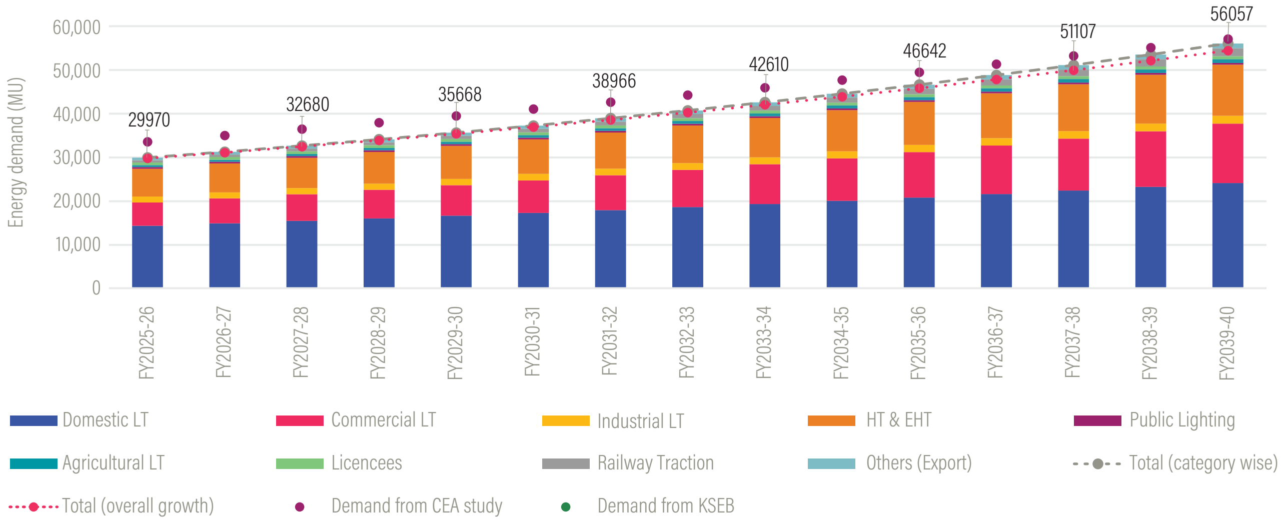
Although the LEAP tool is designed for medium- to long-term modeling, it cannot be used for making dispatch-level decisions. Further, LEAP considers priority of fuel sources based on a simplistic assumption of merit order of energy sources, which is not based on variable cost parameters and does not consider T&D load flow constraints. The scenarios developed in this study and our observations are limited by the availability and reliability of relevant publicly available supply- and demand-side data sets for Kerala. Also, the use of power outages as a tool to manage demand is not factored into the model. Observations made from the scenarios are indicative of future conditions, and energy planners should revise them if updated data sets become available before using the model for energy planning purposes.

Demand projection and scenario description

Demand projection

For all of the scenarios considered in this paper, electricity demand is modeled by considering historical category-wise energy sales in Kerala. Individual category-wise demand is projected to estimate the total demand up to 2040. The categories considered are Domestic LT; Commercial LT; Industrial LT and HT & EHT; Public Lighting; Agricultural LT; Distribution Licensees; Railway Traction; and Others (exports). See Figure 6 for more information.

Figure 6 | **Energy demand projections for 2040**



Note: CEA = Central Electricity Authority. EHT = Extra High Tension. FY = fiscal year. HT = High Tension. LT = Low Tension. MU = million units.
Source: CEA 2025; KSEB 2023.

It is estimated that Kerala's electricity requirement will be around 35,668 MU and 56,057 MU for the years 2030 and 2040, respectively. The projections are in line with historical trends, wherein the largest consumption is from Domestic LT consumers, primarily for household use. This is followed by the Commercial LT category, which consists of commercial establishments, shops, and so on.

The demand from electric vehicles (EVs) is currently accounted for in the Domestic and Commercial LT categories. A review of the literature and author analysis point to an EV demand between 439 MU and 1,133 MU by 2030 and about 1,286 MU by 2040 (CSTEP 2024; KSEB 2025a). Because this demand is relatively low compared to the overall year-wise demand, this is not represented as a separate category but is accounted for under the existing categories.

Scenario description

Scenarios are representations of future energy systems and are constructed based on specific economic conditions, trends, and possibilities (Halkos et al. 2015). Simply put, a scenario is used to describe what could happen under different assumptions or policy choices. A scenario uses a set of user-defined conditions to model parameters that are expected to change over time. Multiple scenarios are generated and compared to derive insights regarding how planned or proposed mitigation actions might impact future GHG emissions and, thus, help achieve targets and desired outcomes (GIZ 2017). First, we model a BAU scenario to represent the future electricity sector demand and emissions if the state plans to continue the current policy regime. We then develop alternative scenarios to compare with BAU: High Renewables, Low Thermal (Nonrenewal of Expiring Thermal PPAs), and Zero Thermal 2040. Appendix E gives detailed descriptions of the modeled scenarios. Table 2 summarizes the scenarios and the key capacity considerations used to model these scenarios.

Table 2 | **Summary of the scenarios, sub-scenarios, and key capacity considerations**

SCENARIO	SUB-SCENARIO	SOLAR	WIND	HYDRO	NUCLEAR	THERMAL	OTHERS
BAU		4,000 MW by 2030 6,000 MW by 2040 ~300 MW/year	115 MW by 2030 231 MW by 2040 (historical growth)	3,105 MW by 2030 3,400 MW by 2040 (historical growth)	CGS share: same (historical trend)	State, CGS, LTOA: same historical trend)	-
High Renewables	High Solar	4,000 MW by 2030 10,000 MW by 2040 ~700 MW/year	Same as BAU	Same as BAU	Same as BAU	Same as BAU	-
	High Solar and Wind	4,000 MW by 2030 10,000 MW by 2040 ~700 MW/year	115 MW by 2030 1,115 MW by 2040	Same as BAU	Same as BAU	Same as BAU	-
Low Thermal (Nonrenewal of Expiring Thermal PPAs)		Same as BAU	Same as BAU	Same as BAU	Same as BAU	Reduc-tion per PPA expiry schedule	-
	Compensating (Solar)	4,000 MW by 2030 10,000 MW by 2040 ~700 MW/year	Same as BAU	Same as BAU	Same as BAU	Reduc-tion per PPA expiry schedule	-
	Compensating (Solar + Wind)	4,000 MW by 2030 10,000 MW by 2040 ~700 MW/year	115 MW by 2030 1,115 MW by 2040	Same as BAU	Same as BAU	Reduc-tion per PPA expiry schedule	-
	Compensating (Solar + Wind + LTOA)	4,000 MW by 2030 10,000 MW by 204 ~700 MW/year	115 MW by 2030 1,115 MW by 2040	Same as BAU	Same as BAU	Reduc-tion per PPA expiry schedule for CGS; LTOA capacities retained	-
	Compensating (Solar + Wind + LTOA + OA RE)	4,000 MW by 2030 10,000 MW by 2040 ~700 MW/year	115 MW by 2030 1,115 MW by 2040	Same as BAU	Same as BAU	Reduc-tion per PPA expiry schedule for CGS; LTOA capacities retained	Reductions in thermal capacity compensated by 2× OA RE addi-tions: 440 MW by 2030 and 2,860 MW by 2040
Zero Thermal 2040		4,000 MW by 2030 10,000 MW by 2040 ~700 MW/year	115 MW by 2030 1,115 MW by 2040	Same as BAU	Same as BAU	Reduced gradually to be 0MW by 2040	-
	Compensat-ing (Balanced through RE Capacity Additions + OA RE)	4,000 MW by 2030 10,000 MW by 2040 ~700 MW/year	115 MW by 2030 1,115 MW by 2040	Same as BAU	Same as BAU	Reduced gradually to 0 MW by 2040	Reductions in thermal capacity compensated by OA RE additions: 6,500 MW by 2030 and 16,000 MW by 2040

Note: BAU = Business-as-Usual. CGS = central generating station. LTOA = long-term open access. MW = megawatt. OA = open access. PPA = power purchase agreement. RE = renewable energy. Installed renewable capacity in Kerala (as of July 2024) was 1,507.49 MW (1,164.97 MW solar, 276.52 MW SHP, 63.50 MW wind, 2.5 W bioenergy); solar power capacity from 322.79 MW ground-mounted solar; 817.25 MW from rooftop solar; and the remaining 24.93 MW from off-grid solar and PM KUSUM components (CEA 2024b; MNRE 2024).

Source: WRI India authors.

Analysis and insights

This section presents insights into overall capacity and generation growth, capacity additions of various electricity-generating sources, and the share of generation under the considered scenarios.

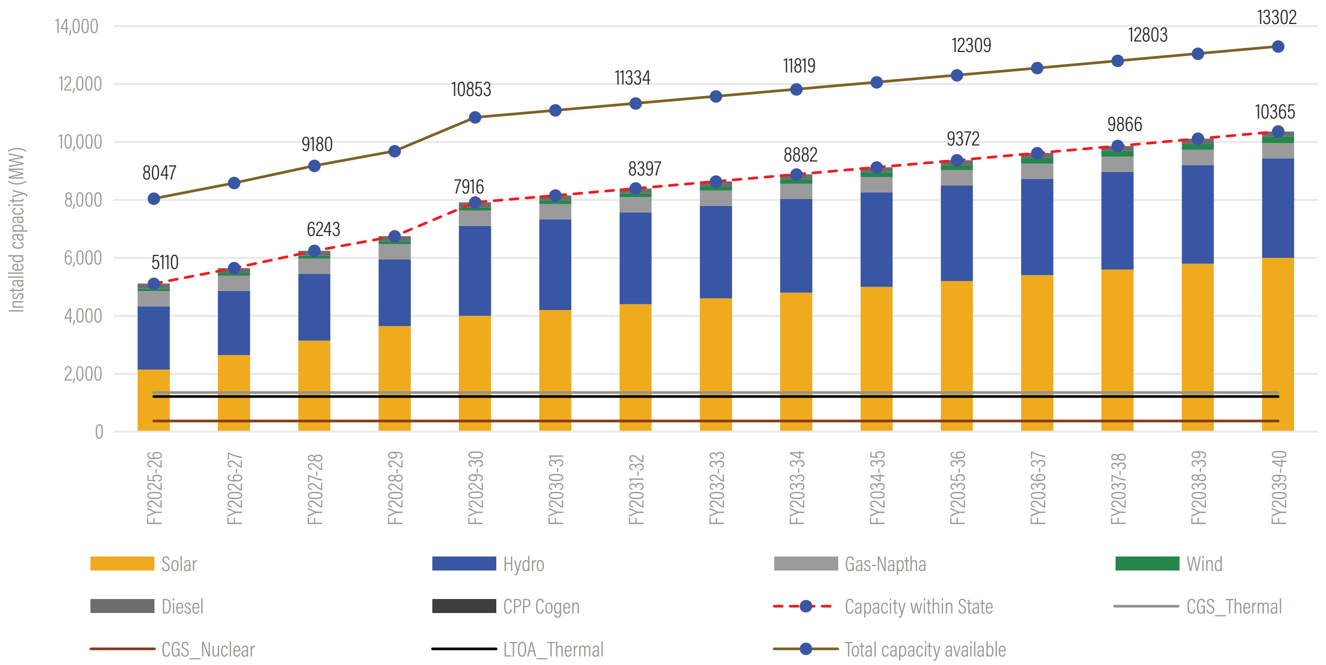
Scenario 1: BAU

Capacity additions of the various generating sources are considered for the BAU scenario, as mentioned in the subsection "Scenario description". Additionally, Table 2 summarizes the values used for the capacity addition estimations up to 2040.

As shown in the bar graph in Figure 7, Kerala's total installed capacity is expected to increase to 10,365 MW by FY2039–40. This capacity is derived from various generating sources: solar (represented in yellow), hydro (represented in blue), wind (represented in green), and various other thermal sources (represented in gray). Additionally, considering the capacity allocation from CGSs and LTOA contracts as power purchases, the capacity of energy-generating sources available to Kerala is projected at 13,302 MW (blue dot on brown line). It can be observed from the bar graphs for FY2025–26 to FY2039–40 that the increase in total installed capacity will be driven mainly by solar (evident from the increasing share of yellow), supported by wind and hydro. Here, the shares of CGS and LTOA are expected to remain unchanged because their PPAs will be renewed.

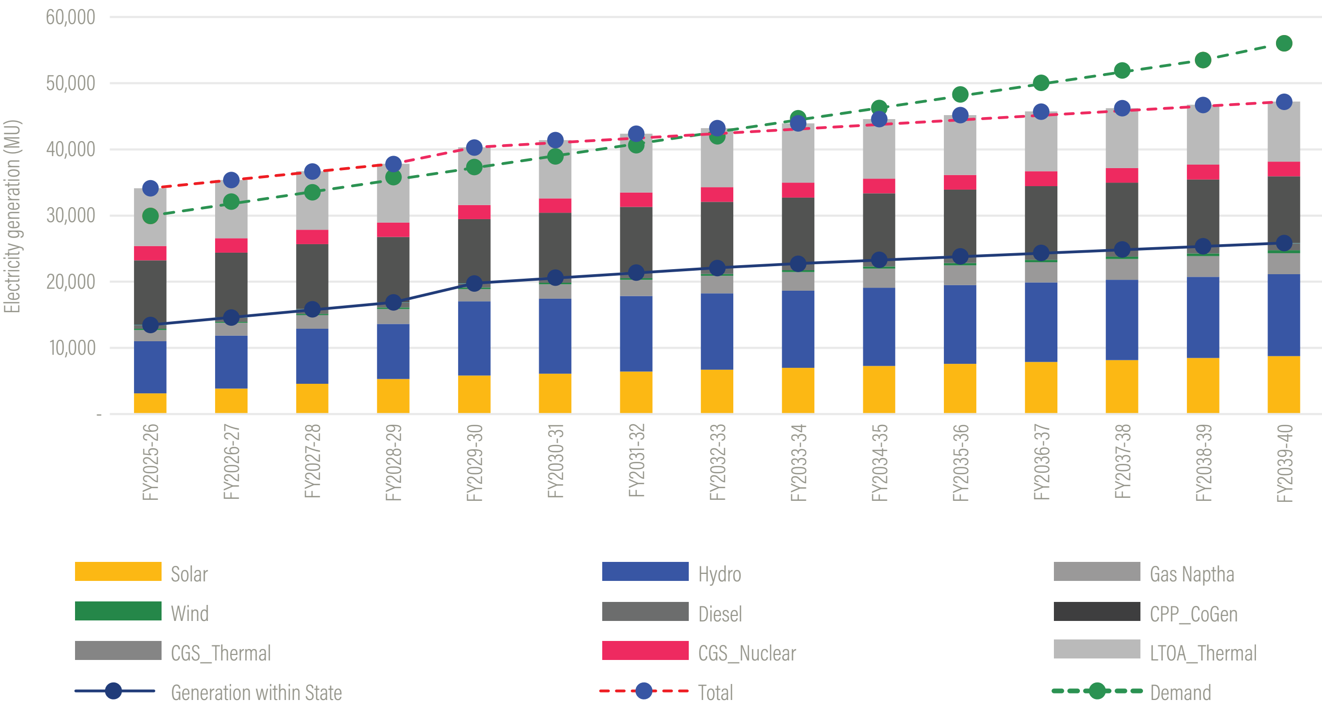
Solar capacity is projected to increase from an estimated 4,000 MW in FY2029–30 to close to the maximum value of about 6,000 MW by FY2039–40. Hydro is likely to increase to 3,437 MW by FY2039–40 from 3,105 MW in FY2029–30. Wind capacity is estimated to increase to 230 MW by FY2039–40 from the FY2029–30 estimate of 115 MW and the current capacity of 70 MW. Thermal's share in the total available capacity will decrease from 52 percent currently to 33 percent in FY2029–30 and to 25 percent by FY2039–40. The shares of installed capacities are as follows: thermal (25 percent), hydro (26 percent), solar (45 percent), nuclear (3 percent), and wind (2 percent). The installed capacity projections

Figure 7 | **Estimate of installed capacity growth: BAU scenario**



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access.
Source: WRI India authors.

Figure 8 | **Electricity generation projections: BAU scenario**



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. The capacity utilization factors (CUFs) for the analysis are obtained from KSEB (2023), based on the average values for a technology.
Source: WRI India authors and Heaps (2026).

estimate thermal's share to be a quarter of the total installed capacity.

Figure 7 provides an overview of the installed capacity of various generating sources. It is useful to compute the shares of fossil fuel and renewable sources available to Kerala to meet its demand. However, for the actual electricity generated from these sources, see Figure 8. The bar graphs represented in shades of gray and black represent generation from fossil fuel sources.

The shares of electricity generation in FY2039–40 from the available sources are as follows: thermal (37 percent), hydro (20 percent), solar (14 percent), nuclear (4 percent), wind (1 percent), and other purchases (16 percent). According to the generation profile, dependence on fossil fuels would remain high despite the solar capacity additions. Hence, it is worthwhile exploring whether higher-capacity renewable additions could help Kerala meet its demand and increase the renewable share.

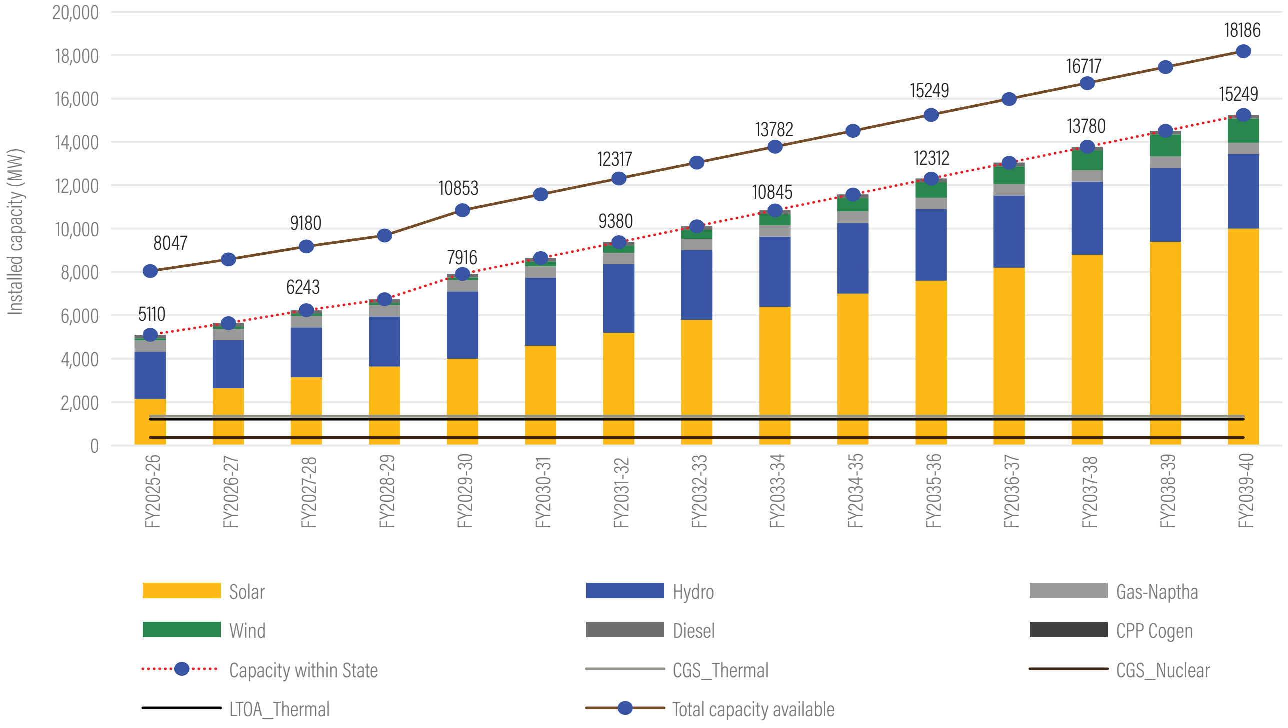
It is also observed that a shortfall in electricity generated is expected after FY2034–35, as indicated by demand (the green dotted line) exceeding total generation (the red dotted line). It can be inferred that capacity additions per the BAU scenario alone may not be sufficient to meet the demand beyond FY2034–35. It is likely that this shortfall would need to be addressed through further capacity additions within Kerala or OA agreements.

The share of RE in the total energy mix is increasing (see the graphs in Figures 7 and 8). This increase in RE share will lead to a higher RE procurement cost. See Appendix A and Figure B-1 of Appendix B for the changes in unit cost of electricity from various sources and year-wise renewable electricity procurement costs. From the financial analysis, the cost of procurement of renewable electricity will be approximately INR 925 crore[2] in FY2025-26 and INR 2,194 crore in FY2039–40 (see Figure B-1 of Appendix B). No financial savings result from the abatement of thermal electricity because it is required to meet Kerala's electricity requirements.

Scenario 2: High Renewables

Table 2 summarizes this scenario, and Appendix E gives a detailed explanation. This scenario consists of two sub-scenarios: High Renewables–High Solar and High Renewables–High Solar and Wind. The former considers accelerated capacity additions in solar alone, whereas the latter also considers wind capacity additions. Figures 9 and 10 depict the High Renewables–High Solar and Wind sub-scenario. Appendix B provides data on the High Renewables–High Solar sub-scenario.

Figure 9 | **Installed capacity growth estimate: High Renewables-High Solar and Wind sub-scenario**



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access.
Source: WRI India authors.

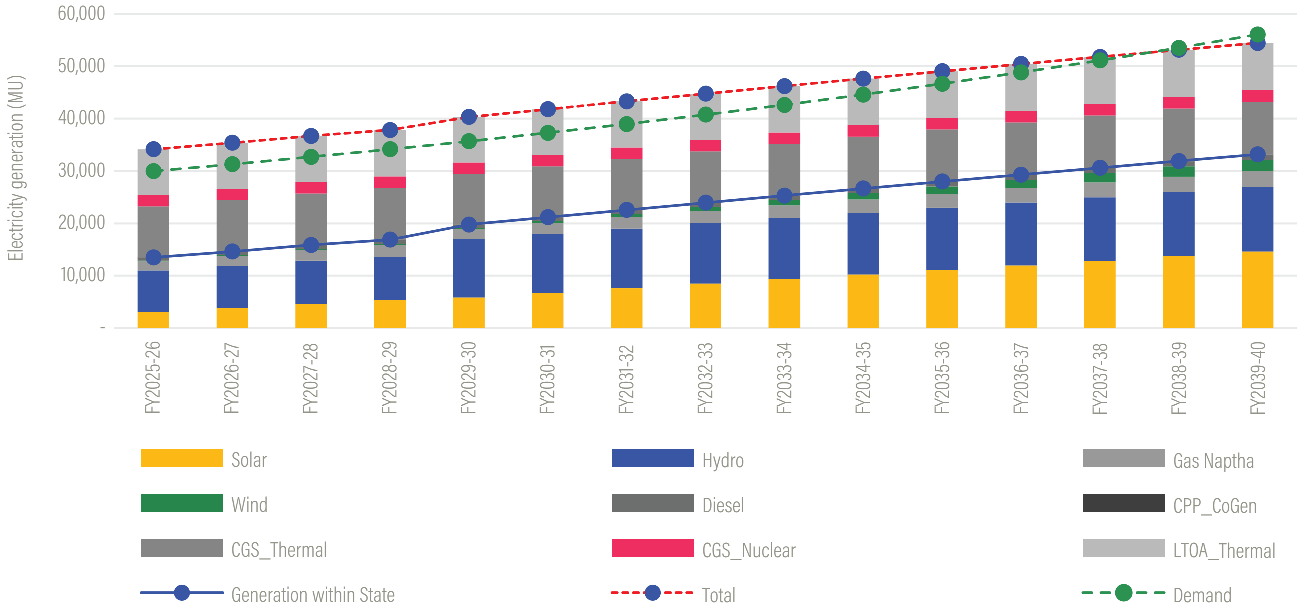
In the case of High Renewables–High Solar, Kerala's installed capacity is expected to increase to 14,367 MW. Considering the capacity allocation from CGS and LTOA, the total available capacity is projected at 17,302 MW. Increase in installed capacity will be driven mainly by the growth of solar (see the yellow section of the bar graph in Figure B-2 of Appendix B). In the case of High Renewables–High Solar and Wind, Kerala's installed capacity is expected to increase to 15,249 MW. Considering the capacity allocation from CGS and LTOA, the total available capacity is projected at 18,186 MW. Increase in installed capacity will be driven mainly by the growth of solar, with wind contributing to a lesser extent. In both cases, the shares of CGS and LTOA are expected to remain the same because their PPAs will be renewed (Figure 9).

The installed capacities of the various generating sources are as follows: solar capacity will reach 10,000 MW by FY2039–40. Appendix C gives an indicative potential of the various renewable sources in Kerala. In the High Renewables–High Solar scenario, hydro is likely to increase to 3,437 MW from 3,105 MW in FY2029–30, as in the BAU. Increase in wind capacity is estimated at 230 MW from the FY2029–30 estimate of 115 MW and 70 MW available currently, as in the BAU for High Renewables–High Solar. For High Renewables–High Solar and Wind, the FY2040 wind capacity is estimated at 1,115 MW.

For the High Renewables–High Solar sub-scenario, thermal's share in total available capacity will decrease from 52 percent currently to 33 percent in FY2029–30 and to 19 percent by FY2039–40. The capacity shares of various sources are as follows: thermal (19 percent), hydro (20 percent), solar (58 percent), nuclear (2 percent), and wind (1 percent). For High Renewables–High Solar and Wind, the installed capacity percentage from wind increases to about 6 percent, with the contributions from the other sources remaining relatively the same.

See Figure 10 for detailed information on the actual electricity generated from these sources. The bar graphs represented in shades of gray and black represent generation from fossil fuel sources. The other sources are represented in different colors, as detailed in the graph legend. For both sub-scenarios, dependence on fossil fuels would be high. The shares of electricity generation in FY2039–40 from the available sources are as follows: thermal (37 percent), hydro (20 percent), solar (23 percent), nuclear (4 percent), and wind (3 percent).

Figure 10 | **Electricity generation projections: High Renewables-High Solar and Wind sub-scenario**



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access.
Source: WRI India authors.

The analysis shows that the total electricity generation from the various sources meets the total electricity demand of the state until FY2037–38 without any shortfalls (represented by the placement of the red dotted line above the green dotted line in Figure 10). However, the percentage of excess generation is low in the High Renewables–High Solar sub-scenario (see Figure B-3 of Appendix B). Considering wind capacity additions along with solar, as modeled through the High Renewables–High Solar and Wind sub-scenario, it is observed that the shortfall is minimized and excess generation is improved to better meet T&D losses (Figure 10).

The financial analysis revealed that the cost of electricity procurement in the High Renewables scenario increases steadily from INR 925 crore in FY2025-26 to about INR 4,016 crore in FY2039–40. This cost is higher than that in the BAU scenario due to accelerated adoption of solar power plants along with wind energy (see Figures B-4 and B-5 of Appendix B).

Scenario 3: Low Thermal (Nonrenewal of Expiring Thermal PPAs)

In the BAU and High Renewables scenarios, we find that the share of fossil fuels in total energy generated is high. This is mainly due to Kerala's high dependence on electricity imports and legacy PPAs, primarily of thermal origin. To further reduce the share of fossil fuels and improve the renewable share for meeting the state's targets, another scenario is modeled, namely, Low Thermal (Nonrenewal of Expiring Thermal PPAs), where existing long-term PPAs are not renewed upon expiry and the resulting loss of energy generation is compensated through renewable capacity additions. Table 2 summarizes this scenario, and the section titled "Scope, research questions, methodology, and limitations" gives a detailed explanation.

Various sub-scenarios are modeled to capture the result of various capacity addition initiatives. First, a sub-scenario is modeled, which considers only the expiry of existing PPAs, with other technologies increasing in accordance with the BAU scenario. Figure B-6 of Appendix B shows the growth and shares of various installations for this sub-scenario, which is useful for identifying the years when electricity shortfalls commence, with total generation unable to meet the state's electricity demand. It is observed that a shortfall in electricity generation occurs earlier than in the BAU (by FY2033–34). This is indicated by the green dotted line crossing over the red dotted line in Figure B-7 of Appendix B. The magnitude of the shortfall in electricity generation after FY2033–34 is also high.

It is prudent to check whether or not higher-capacity solar additions can address some of the shortfall and delay the year of its onset. A sub-scenario is modeled considering accelerated capacity additions of solar alone (per the High Renewables–High Solar sub-scenario), with the capacities of other sources maintained at BAU levels. Figure B-9 of Appendix B shows the installed capacity shares of the various sources.

From the electricity generation profile shown in Figure B-10 of Appendix B, we observe that a shortfall in electricity generation occurs even when the initial year of the electricity shortfall is shifted. To further explore the possibility of reducing the electricity shortfall and meeting demand, another sub-scenario is modeled that considers accelerated capacity additions of both solar and wind. Figure B-12 gives an overview of the capacity growth of the various generating sources. The electricity-generating profile in Figure B-13 shows that although electricity generation improves, a shortfall in electricity generation occurs toward the end of FY2035–36. Further interventions are required to address all the electricity requirements.

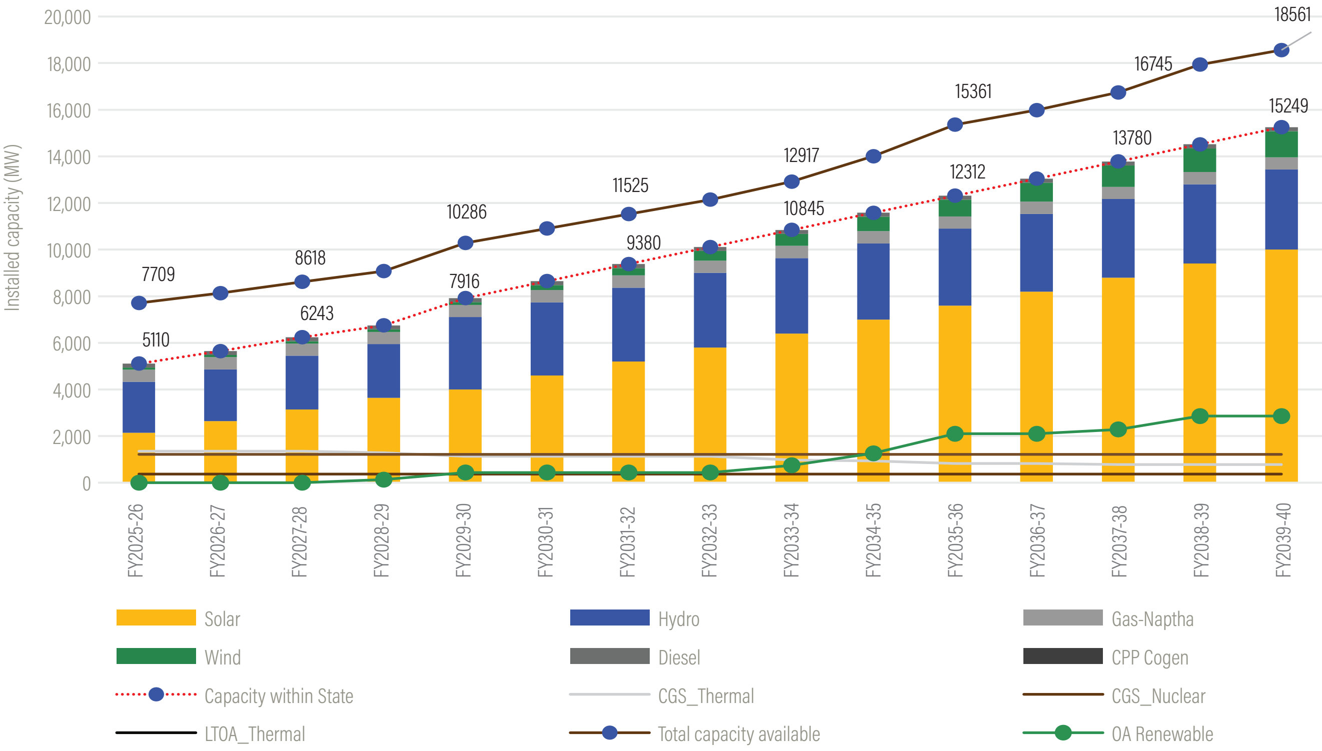
In addition to increasing wind and solar capacity, another sub-scenario is modeled in which, to help address some of the shortfalls, LTOA contracts are not reduced. Figure B-15 shows the year-wide capacity shares, and Figure B-16 shows the improvement in electricity generation over other generation profiles (shown in Figures B-10 and B-13), especially for FY2039–40. However, a shortfall persists beyond FY2035–36. To fully address the electricity demand and consider the need for excess generation to meet T&D losses, other renewable capacity additions over and above the existing capacities are considered. This is modeled as the Low Thermal (Nonrenewal of Expiring Thermal PPAs)–Compensating (Solar + Wind + LTOA + OA RE) sub-scenario.

The shares of various generating sources under this sub-scenario are as follows: thermal (14 percent), hydro (19 percent), solar (54 percent), nuclear (2 percent), wind (6 percent), and other RE (5 percent). Figure 11 shows the year-wise capacity growth, facilitating a detailed understanding of the various installed capacities. Energy generation is considerable improved, and supply is able to largely meet demand in this scenario, with only slight shortfalls when nearing FY2039–40 (see Figure 12). The shares of electricity generation in FY2039–40 are as follows: thermal (29 percent), hydro (20 percent), solar (23 percent), nuclear (3 percent), wind (3 percent), and other RE (22 percent) (see Figure 12). The total share of RE is 48 percent and that of RE and hydro combined is about 68 percent.

In this sub-scenario, we find that the total share of renewable generation is nearly 50 percent. However, thermal's share is still high at, 29 percent. Hence, an exploratory scenario is considered that estimates the interventions and capacities required for Kerala to move away from thermal sources.

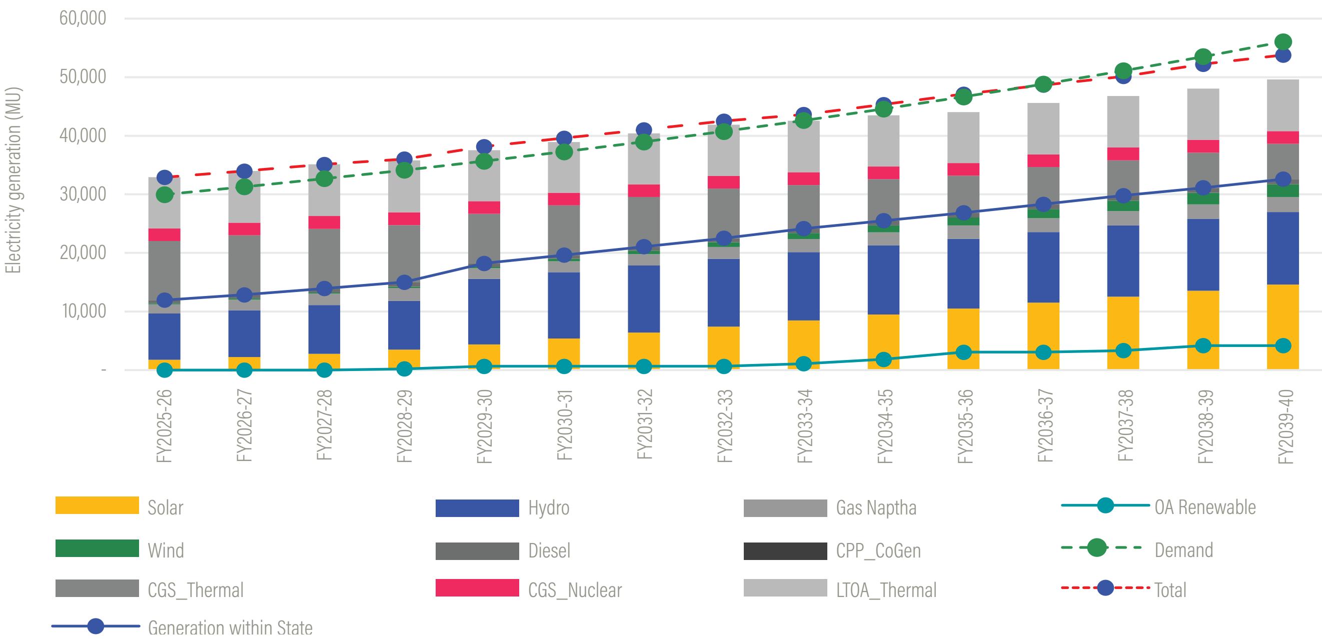
This scenario is marked by financial savings from nonrenewal of existing thermal PPAs. For the first sub-scenario—in which capacity additions are maintained at BAU levels and PPAs are not renewed—from FY2028–29 onward, savings will occur due to the expiry of these PPAs. From FY2028–29 to FY2034–35, RE procurement cost will be on the higher side, but after FY2035–36, savings from the abatement of thermal electricity will dominate and increase significantly in FY2039–40. In FY2028–29, the savings will be INR 194 crore, and in FY2039–40, the savings will reach INR 6,935 crore, which is more than double the RE electricity procurement cost (see Figure B-8 of Appendix B). In the next sub-scenario (compensating with solar), the savings from nonrenewal of existing PPAs can reach INR 6,935 crore in FY2039–40, when the RE electricity procurement cost will be INR 3,581 crore (Appendix B, Figure B-11). In the next sub-scenario (compensating with wind and solar), the power purchase cost is higher than that in the High Solar sub-scenario: due to the accelerated adoption of wind energy, the RE procurement cost will reach INR 4,016 crore in 2040. The savings from the abatement of thermal electricity are almost double the RE procurement cost for FY2039–40 because a large number of PPAs will expire in FY2039–40, but for the remaining years, the savings are less than the RE procurement cost. However, these sub-scenarios exhibit electricity shortfalls, as discussed previously (Appendix B, Figure B-14).

Figure 11 | **Estimate of installed capacity growth: Low Thermal (Nonrenewal of Expiring Thermal PPAs)-Compensating (Solar + Wind + LTOA + OA RE) sub-scenario**



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. OA = open access. The total capacity availability to the state (brown line) is the sum of the installed capacity within the state (red dotted line) and CGS thermal, CGS nuclear, LTOA thermal, and OA renewables.
Source: WRI India authors.

Figure 12 | **Projections of electricity generation: Low Thermal (Nonrenewal of Expiring Thermal PPAs)-Compensating (Solar + Wind + LTOA + OA RE) sub-scenario**



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. The total generation (dotted red line) includes the generation from the various generating sources (stacked bar graphs) available to the state and the generation from OA renewables (light blue line).
Source: WRI India authors.

For the next sub-scenario (in which LTOA contracts are retained), savings from the abatement of thermal electricity will be less than those in other nonrenewal of expiring PPAs scenarios because the LTOAs are retained. Annual savings in all the analyzed years are less than the RE procurement cost. However, more than 60 percent of the RE procurement cost can be offset from these savings in FY2039–40. In FY2039–40, the RE procurement cost can reach INR 4,016 crore and savings will be INR 2,426 crore because LTOAs are retained. Finally, when additional renewable capacity additions are considered to enhance excess generation, it is observed that half of the RE procurement cost can be offset through the abatement of thermal electricity from FY2029–30 onward (see Figures B-17 and B-18 of Appendix B).

Scenario 4: Zero Thermal 2040

Considering the high share of thermal in the other modeled scenarios, it is necessary to consider an exploratory scenario that examines the implications of achieving zero thermal contributions by FY2039–40. This is modeled in the Zero Thermal FY2040 scenario and its sub-scenario. Table 2 summarizes this scenario, and Appendix E gives a detailed explanation. This scenario considers only a gradual decline in thermal capacity with the aim of achieving zero contributions by FY2039–40. In this sub-scenario, renewable capacities grow in accordance with the High Renewables scenario. This sub-scenario is useful for understanding the electricity generation profiles, the year when shortfalls begin, and so on. Figure B-19 of Appendix B gives the year-wise installed capacity shares of the various sources.

Figure B-20 shows that reducing thermal capacity to zero by FY2039–40 results in severe generation shortfalls in the absence of other major interventions, as evidenced by the crossing of the green and red dotted lines. The figure also shows that shortfalls in electricity generation occur as early as in FY2027–28. It is clear that more renewable capacity would be required to compensate for the reduction in thermal capacity and meet the electricity demand.

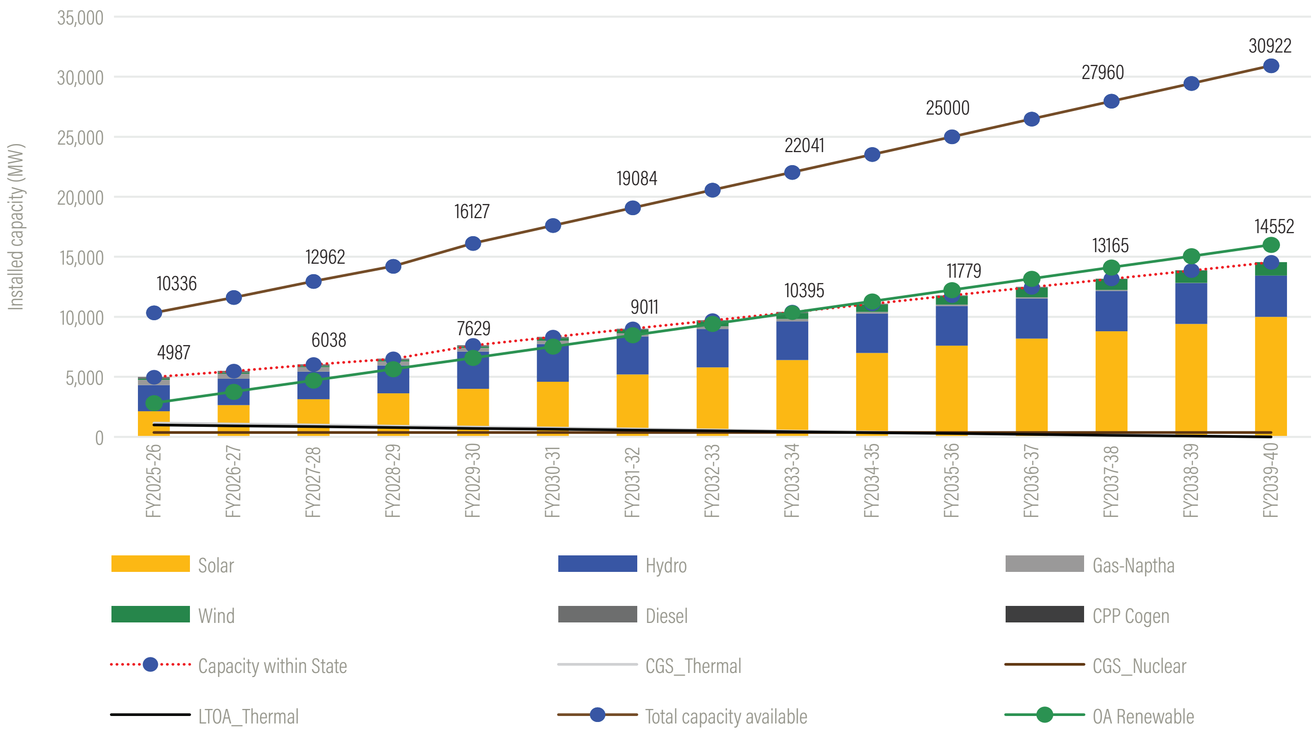
In the modeled sub-scenario, reductions in thermal capacity are compensated by renewable additions to meet most of the electricity demand. This is modeled as the Zero Thermal 2040–Compensating (Balanced through RE Capacity Additions + OA RE) sub-scenario. Under this sub-scenario, the shares of various generating sources within the state are as follows: thermal (0 percent), hydro (11 percent), solar (32 percent), nuclear (1 percent), wind (4 percent), and other RE (51 percent). (Other RE represents renewable capacity allocations to Kerala other than from renewable installations within the state.) Figure 13 provides an overview of the installed capacity of various generating sources for this sub-scenario.

Figure 14 shows that in this sub-scenario, all the electricity is generated from renewables, hydro, and nuclear sources, with renewable sources contributing 77 percent. The shares of electricity generation in FY2039–40 are as follows: thermal (0 percent), hydro (20 percent), solar (23 percent), nuclear (3 percent), wind (3 percent), and other RE (51 percent). If Kerala is to move away from thermal, it will require at least 27 GW of renewable capacity.

In the Zero Thermal 2040 scenario, savings are greater than those in all the other scenarios because thermal PPAs are being curtailed at a certain rate. The financial savings from the abatement of thermal electricity can reach INR 1,094 crore in FY2025-26, gradually increasing to INR 10,870 crore in FY2039–40. The RE procurement cost can reach INR 6,036 crore. However, the procured RE will not be sufficient to meet the anticipated electricity demand in FY2039–40.

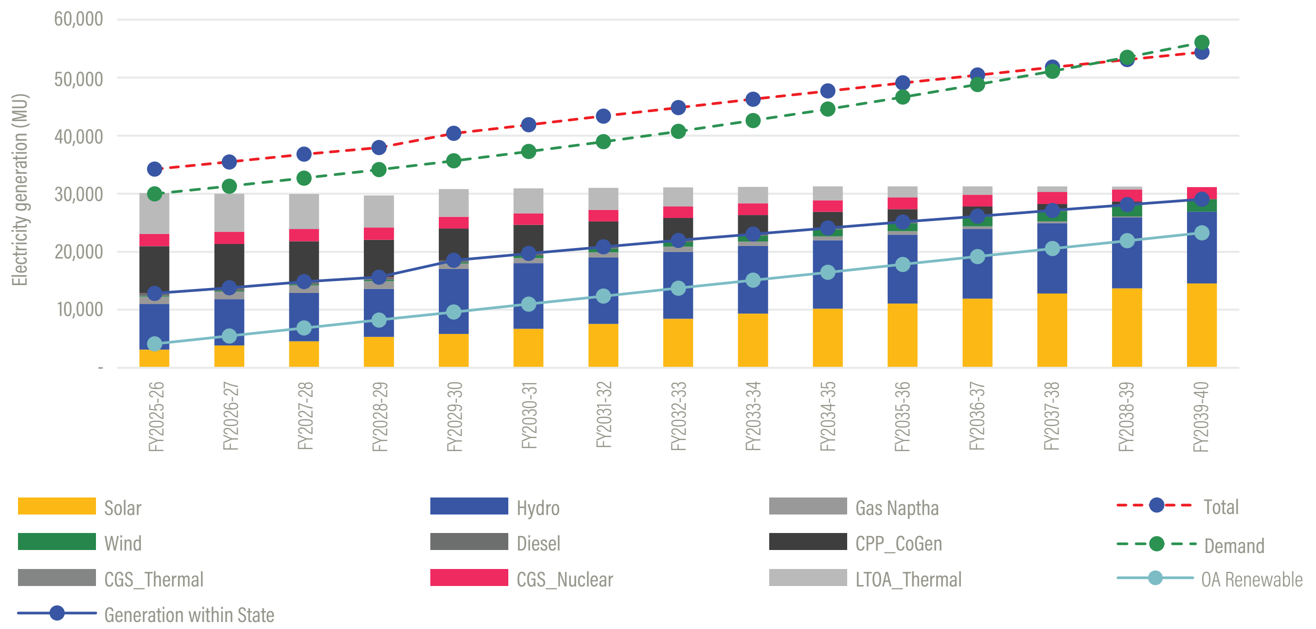
In the Zero Thermal 2040–Compensating (Balanced through RE Capacity Additions + OA RE) sub-scenario, similar to the zero thermal scenario, savings occur through the gradual curtailment of thermal contracts from FY2025–26 onward. In FY2025–26, the savings can reach INR 1,399 crore, increasing to INR 10,870 crore in FY2039–40. These savings could be utilized for RE procurement from OA sources along with establishing RE generation within the state. In the period FY2025–26 to FY2033–34, the RE procurement cost dominates; in FY2034–35, it becomes similar to savings from the abatement of thermal electricity; and from FY2035–36 onward, savings from the abatement of thermal electricity start dominating. In FY2039–40, the savings from the abatement of thermal electricity and the cost of procuring RE electricity are INR 10,870 crore and INR 8,963 crore, respectively (see Figures B-21 and B-22 of Appendix B).

Figure 13 | Estimate of installed capacity growth: Zero Thermal 2040-Compensating (Balanced through RE Capacity Additions + OA RE) sub-scenario



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. The total capacity availability to the state (brown line) is the sum of the installed capacity within the state (red dotted line) and CGS thermal, CGS nuclear, LTOA thermal, and OA renewables.
Source: WRI India authors.

Figure 14 | Projections of electricity generation: Zero Thermal 2040-Compensating (Balanced through RE Capacity Additions + OA RE) sub-scenario



Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. The total generation (dotted red line) includes the generation from the various generating sources (stacked bar graphs) available to the state and the generation from OA renewables (light blue line).
Source: WRI India authors.

Summary of analysis and insights

Table 3 summarizes the information provided in the analysis and insights section.

Table 3 | **Summary of the key insights into the different scenarios for FY2039–40**

	DEMAND MET	THERMAL CAPACITY (%)	WIND + SOLAR CAPACITY (%)	THERMAL GENERATION (%)	WIND + SOLAR GENERATION (%)
BAU	No	25	47	37	15
HIGH RENEWABLES					
High Solar	No	–	–	–	–
High Solar and Wind	Yes	18	61	37	26
LOW THERMAL (NONRENEWAL OF EXPIRING THERMAL PPAS)	No	–	–	–	–
Compensating (Solar)	No	–	–	–	–
Compensating (Solar +Wind)	No	–	–	–	–
Compensating (Solar + Wind + LTOA)	No	–	–	–	–
Compensating (Solar + Wind + LTOA + OA RE)	Yes	13	54	32	42
ZERO THERMAL 2040	No	–	–	–	–
Compensating (Balanced through RE Capacity Additions + OA RE)[a]	Yes	0%	87%	0%	77%

Note: LTOA = long-term open access. OA = open access. RE = renewable energy. Percentages are reported for a sub-scenario only if that sub-scenario meets the electricity demand.

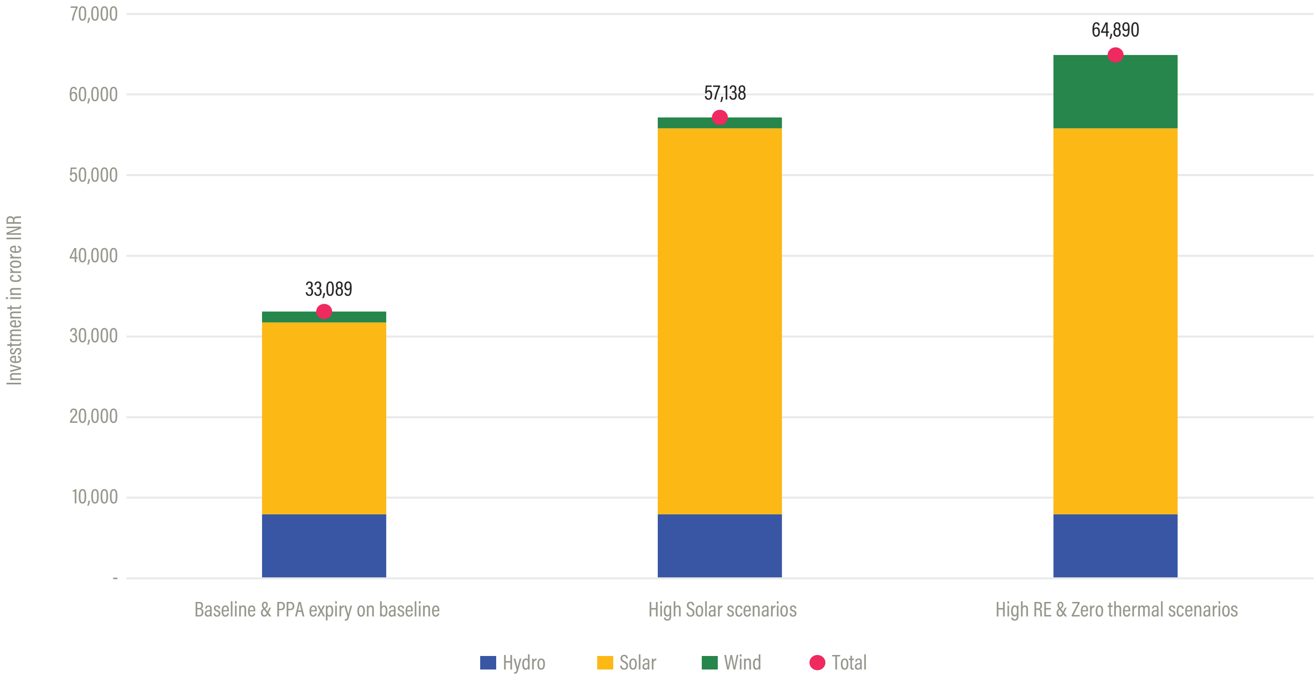
a. A small shortfall in FY2039–40. "Wind + solar capacity" includes both OA renewable capacity and generation.

Source: WRI India authors.

Figure 15 presents the total investment requirement for implementing RE projects in Kerala, which utilize the available potential under different scenarios from FY2025–26 to FY2039–40. To realize the available RE potential in an accelerated phase, the investment requirement could reach INR 64,890 crore. This investment requirement is 96 percent higher than that in the BAU scenario, which is INR 33,089 crore. This cost includes the investment requirements for the proposed hydropower development by KSEB. However, the investment required for the development of T&D infrastructure and storage facilities to manage demand are not included in Figure 15.

Development of energy storage facilities, including battery energy storage systems (BESS) and T&D infrastructure, is essential to achieve and utilize the projected installed capacity. Multiple studies have projected Kerala's BESS requirement. CEA's resource adequacy (RA) study for Kerala projects a BESS requirement of 550 MW/1,600 Mega Watt hours (MWh) for FY2035–36 (CEA 2025). Another study by CSTEP projects an energy storage requirement of 3.6 GW/7,163 GWh for FY2029–30 and 4.1 GW/8,108 Giga Watt hours (GWh) for FY2039–40 for high RE penetration (CSTEP 2024). The investment required for 4-hour BESS in FY2025–26 will be INR 6.68 crore/MW, which will increase to INR 8.02 crore/MW in FY2039–40. For six-hour storage, the investment requirement will be on the order of INR 8.83 crore/MW to INR 10.72 crore/MW (CEA [2023] and the authors' analysis). Appendix A details the investment requirements. BESS is not the only feasible energy storage system in Kerala; pumped storage hydro (PSH) is another energy storage option, with an estimated potential of 4.4 GW (Kumar et al. 2025).

Figure 15 | **Total investment required from FY2025-26 to FY2039-40 under different scenarios**



Note: PPA = power purchase agreement. RE = renewable energy.
Source: WRI India authors.

Conclusion

Kerala aspires to become a 100 percent RE-based state by 2040 and achieve carbon neutrality by 2050. This issue brief adopts scenario-based modeling using the LEAP tool to examine the likelihood of the state meeting the 2040 target. It also provides insights into Kerala's current electricity landscape and explores multiple low-carbon pathways that Kerala can consider for its RE transition. The brief examines a High Renewables scenario; another scenario in which thermal PPAs are not renewed; and an exploratory scenario that considers the interventions needed to move away completely from thermal sources by 2040.

It is observed that under the BAU scenario, although Kerala can meet its demand until 2030, it continues to rely heavily on thermal power. Even with accelerated additions in solar and wind (up to 10 GW and 1.1 GW, respectively, by 2040), the share of thermal remains high at around 40 percent. Alternative pathways are likely needed to reduce thermal dependence. Nonrenewal of expiring PPAs of mainly thermal origin, compensated by additional renewable capacity—wind and solar, renewable or green energy OA, improves the renewable share. However, dependence on thermal sources is projected to remain at approximately 30%–32% in 2040.

Overall, Kerala's energy transition plan will be unique, considering its ambition of achieving 100 percent RE by 2040, although it has high import dependencies (around 70 percent), with more than 50 percent of the available electricity coming from fossil fuel. Price volatility and grid-level issues make RA planning challenging. Additionally, Kerala has land constraints that pose challenges to the establishment of utility-scale solar and has to depend on distributed RE, including rooftop solar (RTS). Kerala also has ecologically sensitive zones and a high population density, limiting large-scale renewable development. Kerala's renewable potential (especially for wind) is distributed in certain pockets and in high terrain areas.

Studies on Kerala predict an increase in electricity demand due to the adoption of EVs, air-conditioner usage, as well as electric cooking, along with demand from the commercial and industrial sectors, adding to the challenge of electricity planning in the state. Further, Kerala also needs to plan for integrating a high share of RE into the grid through load management, smart grid upgrades, and energy procurement from outside the state. All this needs to be explored in depth to promote meaningful discussions on integrated energy planning in Kerala.

Further, increase in the renewable share and the complete elimination of thermal dependence are challenging, requiring high-capacity renewable allocations. Hence, a multipronged strategy is required: rapid deployment of diverse RE technologies, including floating solar, wind (both large and small turbines), wave energy, and expanded RTS and utility-scale solar; long-term renewable PPAs with out-of-state generators; and decentralized RE solutions. This transition should be supported by policy and regulatory alignment and investments.

Appendix A. Financial calculations and projections

The authors analyzed the financial implications for each scenario by considering future projections of power purchase costs. The power purchase costs for different sources of electricity specified in KSERC tariff order 2018-2023 and 2022-2027 are considered for future projections of electricity costs. Also, the capital investment potential for the capacity expansions needed to cater to the renewable electricity requirements are also computed. The capital costs specified in the National Electricity Plan (NEP) 2022–32 are considered for the analysis. The capital cost from FY2033 to FY2040 is projected considering the growth rate according to NEP 2022–32. Tables A-1 and A-2 present a detailed analysis.

Table A1 | **Capital expenditure projections for power plants, 2022-2032**

	CAPITAL EXPENDITURE IN CRORE INR/MW										
	2022–23	2023–24	2024–25	2025–26	2026–27	2027–28	2028–29	2029–30	2030–31	2031–32	CAGR (%)
Coal	8.56	8.79	9.02	9.26	9.51	9.76	10.02	10.28	10.55	10.83	**2.6**
Hydro	Actual investment by utilities is considered.										
Nuclear	NPCIL data is used for calculations.										
Solar	4.57	4.64	4.71	4.77	4.84	4.91	4.98	5.05	5.19	5.33	**1.7**
Wind	6.16	6.32	6.49	6.66	6.84	7.02	7.21	7.4	7.59	7.79	**2.6**
SHP	6.67	6.85	7.03	7.22	7.41	7.6	7.81	8.01	8.23	8.44	**2.6**
BESS 4 hr	7.78	7.32	6.82	6.68	6.53	6.36	6.18	5.98	6.16	6.34	**2.97**
BESS 6 hr	10.68	10	9.27	9.06	8.83	8.57	8.29	7.99	8.22	8.47	**2.96**

Note: BESS = battery energy storage system. CAGR = compound annual growth rate. hr = hour. INR = Indian rupee. MW = megawatt. NCPIL = Nuclear Power Corporation of India Limited. SHP = small hydro power. Offshore wind is not considered for Kerala.

Source: CEA (2023) and the authors' analysis.

Table A2 | **Capital expenditure projections for power plants, 2032–2041**

	CAPITAL EXPENDITURE (CRORE INR/MW)								
	2032–33	2033–34	2034–35	2035–36	2036–37	2037–38	2038–39	2039–40	2040–41
Coal	11.12	11.41	11.71	12.02	12.34	12.67	13.0	13.35	13.7
Hydro	—	—	—	—	—	—	—	—	—
Nuclear	—	—	—	—	—	—	—	—	—
Solar	5.47	5.62	5.76	5.92	6.07	6.23	6.40	6.57	6.74
Wind	8.00	8.21	8.43	8.65	8.88	9.11	9.35	9.6	9.86
SHP	8.66	8.89	9.13	9.37	9.62	9.87	10.13	10.4	10.68
BESS 4 hr	6.51	6.68	6.86	7.04	7.23	7.42	7.61	7.81	8.02
BESS 6 hr	8.69	8.92	9.16	9.4	9.65	9.91	10.17	10.44	10.72

Note: BESS = battery energy storage system. CAGR = compound annual growth rate. hr = hour. INR = Indian rupee. MW = megawatt. NCPIL = Nuclear Power Corporation of India Limited. SHP = small hydro power. Offshore wind is not considered for Kerala.

Source: CEA (2023) and the authors' analysis.

Cost of electricity from thermal sources

The cost of electricity from thermal power plants consists of fixed and variable charges. The average unit cost of electricity for this analysis is computed using annual spending on electricity per kilowatt-hour of electricity. In 2022, the average unit cost of electricity from thermal sources was INR 3.88 and is expected to increase up to INR 4.23 in 2026 (KSERC 2022). However, for some thermal power plants, the unit cost is as high as INR 5.88 in 2026. The growth rate is 2.16 percent. This growth rate is considered for cost projections from FY2026–27 to FY2040–41. With this growth rate, the average unit cost of thermal electricity will reach INR 5.71 in FY2040–41. Tables A-3, A-4, and A-5 present a detailed analysis.

Cost of electricity from renewables

Solar

The approved cost for procurement of solar electricity from independent power producers (IPPs) shows a declining trend of 4.06 percent from FY2018–19 to FY2026–27. The cost varies from INR 3.9/kWh (kilo watt hours) to INR 2.8/kWh (KSERC 2022). Analysis using this trend will not give realistic cost projections; hence, the rate of decrease from FY2022–23 to FY2026–27—that is, 1.16 percent—is considered for the projections. With this rate of decrease, the average cost of solar electricity will reach INR 2.38/kWh. The additional solar and nonsolar renewable energy (RE) procurement cost from sources other than IPPs will reach as high as INR 2.49 and INR 2.05, respectively, in FY2040–41.

Wind

Similar to the cost of solar electricity, wind IPPs also show a declining trend, from INR 3.74/kWh in FY2018–19 to INR 3.01/kWh in FY2026–27 (KSERC 2022). The rate of decrease is 1.21 percent. With this rate of decrease, the cost is expected to decrease to INR 2.54 in FY2040–41.

Small hydro power

Irrespective of solar and wind, the cost of electricity from small hydro power (SHP) IPPs shows an increasing trend of 0.35 percent. The cost varies from INR 3.48 in FY2018–19 to INR 3.58 in FY2026–27 (KSERC 2022). With this rate of change, the cost of electricity will rise up to INR 3.76 in FY2040–41.

Table A3 | **Procurement cost of thermal electricity by KSEB**

			TOTAL COST INCLUDING FIXED COST (CRORE INR)					UNIT COST OF ELECTRICITY (INR/KWH)					
Power plant	Capacity (MW)	Energy (MU)	2021-22	2022-23	2023-24	2024-25	2025-26	2021-22	2022-23	2023-24	2024-25	2025-26	CAGR (%)
RSPTS Stage I & II	245.14	1,696.81	621.64	680.42	692.81	705.45	718.34	3.66	4.01	4.08	4.16	4.23	4
RSTPS Stage III	61.02	425.93	153.10	170.20	173.20	176.27	179.39	3.59	4.00	4.07	4.14	4.21	4
TALCHER-Stage II	427.03	2,980.96	853.18	1010.68	1027.31	1044.28	1061.59	2.86	3.39	3.45	3.50	3.56	6
Simhadri EXP	85.50	600.03	270.32	288.09	290.81	293.61	296.49	4.51	4.80	4.85	4.89	4.94	2
NLS-II-Stage-1	63.02	422.33	156.88	181.34	184.41	187.55	190.74	3.71	4.29	4.37	4.44	4.52	5
NLC-II-Stage-2	90.01	603.17	223.42	260.44	264.82	269.29	273.84	3.70	4.32	4.39	4.46	4.54	5
NLC-EXP-Stage-1	68.12	464.13	169.42	192.42	194.26	196.15	198.10	3.65	4.15	4.19	4.23	4.27	4
NLC-II EXP	81.10	511.51	252.65	277.52	279.12	280.79	282.53	4.94	5.43	5.46	5.49	5.52	3
MAPS	23.02	122.72	31.56	32.19	32.84	33.49	34.16	2.57	2.62	2.68	2.73	2.78	2
KAIGA Stg I	72.99	389.17	136.97	139.71	142.51	145.36	148.26	3.52	3.59	3.66	3.74	3.81	2
Vallur JV	49.98	350.72	175.75	193.37	195.07	196.83	198.63	5.01	5.51	5.56	5.61	5.66	3
NTPL (Tuticorin JV)	72.53	506.33	248.43	267.56	269.89	272.28	274.75	4.91	5.28	5.33	5.38	5.43	3
Kudgi Unit I II & III	111.84	780.71	418.80	445.65	450.06	454.59	459.26	5.36	5.71	5.76	5.82	5.88	2
NNTPP	32.40	226.17	102.45	116.45	117.00	117.58	118.18	4.53	5.15	5.17	5.20	5.23	4
Total (columns 2 to 8) | weighted average (columns 9 to 13) | average growth rate (column 14)	**1,757.23**	**11,587.81**	**4,443.54**	**4,897.59**	**4,968.49**	**5,040.99**	**5,115.08**	**3.83**	**4.23**	**4.29**	**4.35**	**4.41**	**4**
LTOA													
Maithon Power Limited	150.00	1,034.96	417.99	483.68	484.82	486.01	487.24	4.04	4.67	4.68	4.70	4.71	4
Maithon Power Limited	150.00	1,034.96	417.99	483.68	484.82	486.01	487.24	4.04	4.67	4.68	4.70	4.71	4
DVC-Mejia TPS	100.00	705.51	315.71	362.56	365.58	368.69	371.91	4.47	5.14	5.18	5.23	5.27	4
DVC-Raghunath-pur TPS	50.00	348.06	168.17	180.45	182.10	183.80	185.55	4.83	5.18	5.23	5.28	5.33	2
Total (column 2 to 8) | weighted average (column 9 to 13) | average growth rate (column 14)	**450.00**	**3,123.49**	**1,319.86**	**1,510.37**	**1,517.32**	**1,524.51**	**1,531.94**	**4.23**	**4.84**	**4.86**	**4.88**	**4.90**	**4**

			TOTAL COST INCLUDING FIXED COST (CRORE INR)					UNIT COST OF ELECTRICITY (INR/KWH)					
Power plant	**Capacity (MW)**	**Energy (MU)**	**2021-22**	**2022-23**	**2023-24**	**2024-25**	**2025-26**	**2021-22**	**2022-23**	**2023-24**	**2024-25**	**2025-26**	**CAGR (%)**
DBFOO													
Jindal	200.00	1,497.96	576.63	636.80	631.02	625.22	617.99	3.85	4.25	4.21	4.17	4.13	2
BALCO	100.00	748.98	313.25	342.65	338.35	334.75	330.45	4.18	4.57	4.52	4.47	4.41	1
Total (column 2 to 8) | weighted average (column 9 to 13) | average growth rate (column 14)	**300.00**	**2,246.94**	**889.88**	**979.45**	**969.37**	**959.97**	**948.44**	**3.96**	**4.36**	**4.31**	**4.27**	**4.22**	**2**
MTOA													
Considered INR 0.02/annum increase for 2022–24	270	996.95	318.67	320.6	165.15			3.31	3.33	3.35	3.37	3.39	1
Total (column 2 to 8) | weighted average (column 9 to 13) | average growth rate (column 14)	**2,503.70**	**16,448.07**	**6,342.98**	**7,066.46**	**6,965.95**	**6,858.00**	**6,914.64**	**3.86**	**4.30**	**4.24**	**4.17**	**4.20**	**2.18**

Note: BALCO = Bharat Aluminium Company Limited. CAGR = compound annual growth rate. DBFOO = Design, Build, Finance, Own, and Operate. DVC = Damodar Valley Corporation. INR = Indian rupee. KSEB = Kerala State Electricity Board. LTOA = long-term open access. MTOA = medium-term open access. MU = million units. MW = megawatt. NNTPP = Neyveli New Thermal Power Station. TPS = thermal power station.

Source: KSERC (2022) and the authors' analysis.

Table A-4 | **Procurement cost of nuclear electricity by KSEB**

			TOTAL COST INCLUDING FIXED COST (CRORE INR)					UNIT COST OF ELECTRICITY (INR/KWH)					
Power plant	**Capacity (MW)**	**Energy (MU)**	**2022**	**2023**	**2024**	**2025**	**2026**	**2022**	**2023**	**2024**	**2025**	**2026**	**CAGR (%)**
Kudankulam	273.53	1,507.12	628.97	641.55	654.38	667.47	680.82	4.17	4.26	4.34	4.43	4.52	2

Note: CAGR = compound annual growth rate. INR = Indian rupee. KSBEB = Kerala State Electricity Board. kWh = kilowatt-hour. MU = million units. MW = megawatt.

Source: KSERC (2022) and the authors' analysis.

Table A-5 | Procurement cost of renewable electricity by KSEB

SOURCE	UNIT COST OF ELECTRICITY (INR/KWH)									CAGR (%)
	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26	2026-27	
Wind IPPs	3.74	3.74	3.74	3.74	3.16	3.01	3.01	3.01	3.01	**–1.21**
SHP IPPs	3.48	3.48	3.48	3.48	3.58	3.58	3.58	3.58	3.58	**0.35**
Solar IPPs	3.9	3.9	3.9	3.9	3.3	2.9	2.8	2.8	2.8	**–1.16**
Waste to energy						6.31	6.31	6.32	6.31	
Additional solar RPO requirement		3	3	3	2.82	2.82	2.82	2.82	2.82	**–0.88**
Additional nonsolar RPO requirement		2.9	2.9	2.9	2.44	2.44	2.44	2.44	2.44	**–1.25**

Note: CAGR = compound annual growth rate. INR = Indian rupee. IPPs = independent power producers. KSEB = Kerala State Electricity Board. kWh = kilowatt-hour. RPO = Renewable Purchase Obligation. SHP = small hydro power.
Source: KSERC (2019, 2022) and the authors' analysis.

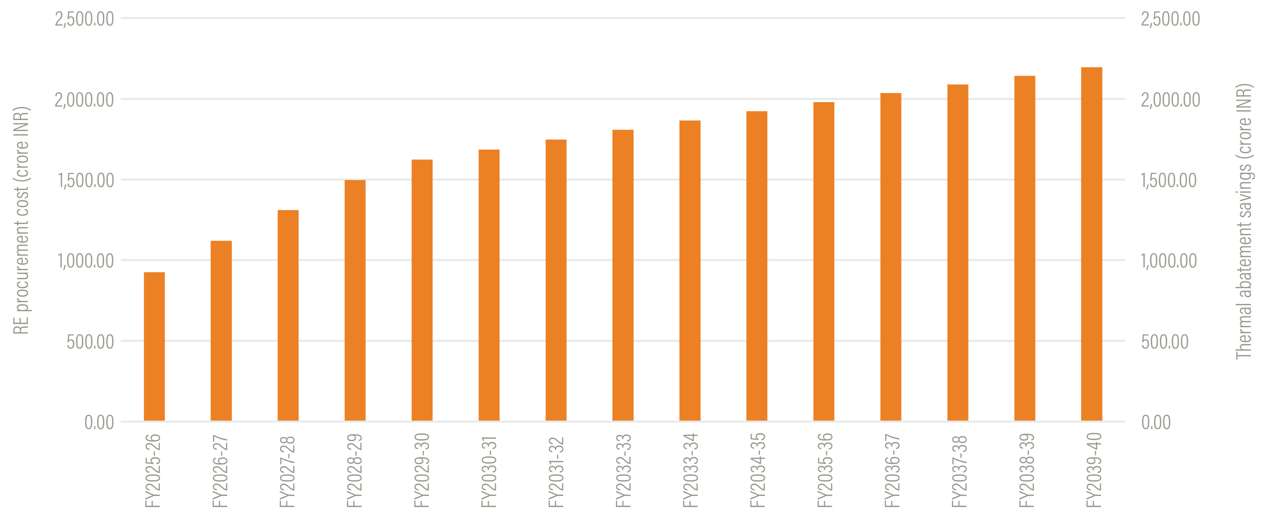
Table A-6 | Tariff projections for electricity procurement from various sources

Source	UNIT COST OF ELECTRICITY (INR/KWH)																	
	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34	2034-35	2035-36	2036-37	2037-38	2038-39	2039-40
Thermal	4.30	4.24	4.17	4.20	4.30	4.39	4.48	4.58	4.68	4.78	4.89	5.00	5.10	5.22	5.33	5.45	5.56	5.69
Nuclear	4.26	4.34	4.43	4.52	4.61	4.70	4.79	4.89	4.99	5.09	5.19	5.29	5.40	5.51	5.62	5.73	5.84	5.96
Wind IPPs	3.01	3.01	3.01	3.01	2.97	2.94	2.90	2.87	2.83	2.80	2.76	2.73	2.70	2.67	2.63	2.60	2.57	2.54
SHP IPPs	3.58	3.58	3.58	3.58	3.59	3.61	3.62	3.63	3.64	3.66	3.67	3.68	3.70	3.71	3.72	3.74	3.75	3.76
Solar IPPS	2.90	2.80	2.80	2.80	2.77	2.74	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.41	2.38
Solar OA	2.82	2.82	2.82	2.82	2.80	2.77	2.75	2.72	2.70	2.67	2.65	2.63	2.60	2.58	2.56	2.54	2.51	2.49
Other RE OA	2.44	2.44	2.44	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.21	2.18	2.15	2.12	2.10	2.07	2.05
RE OA per IEX	5.81	5.49	5.19	4.90	4.63	4.38	4.14	3.91	3.69	3.49	3.30	3.12	2.94	2.78	2.63	2.48	2.35	2.22
Average RE OA	4.13	3.97	3.81	3.67	3.52	3.38	3.24	3.11	2.99	2.88	2.77	2.66	2.56	2.47	2.38	2.29	2.21	2.13

*N*ote: INR = Indian rupee. IEX = Indian Energy Exchange. PPs = independent power producers. kWh = kilowatt-hour. OA = open access. RE = renewable energy.
Source: The authors' analysis.

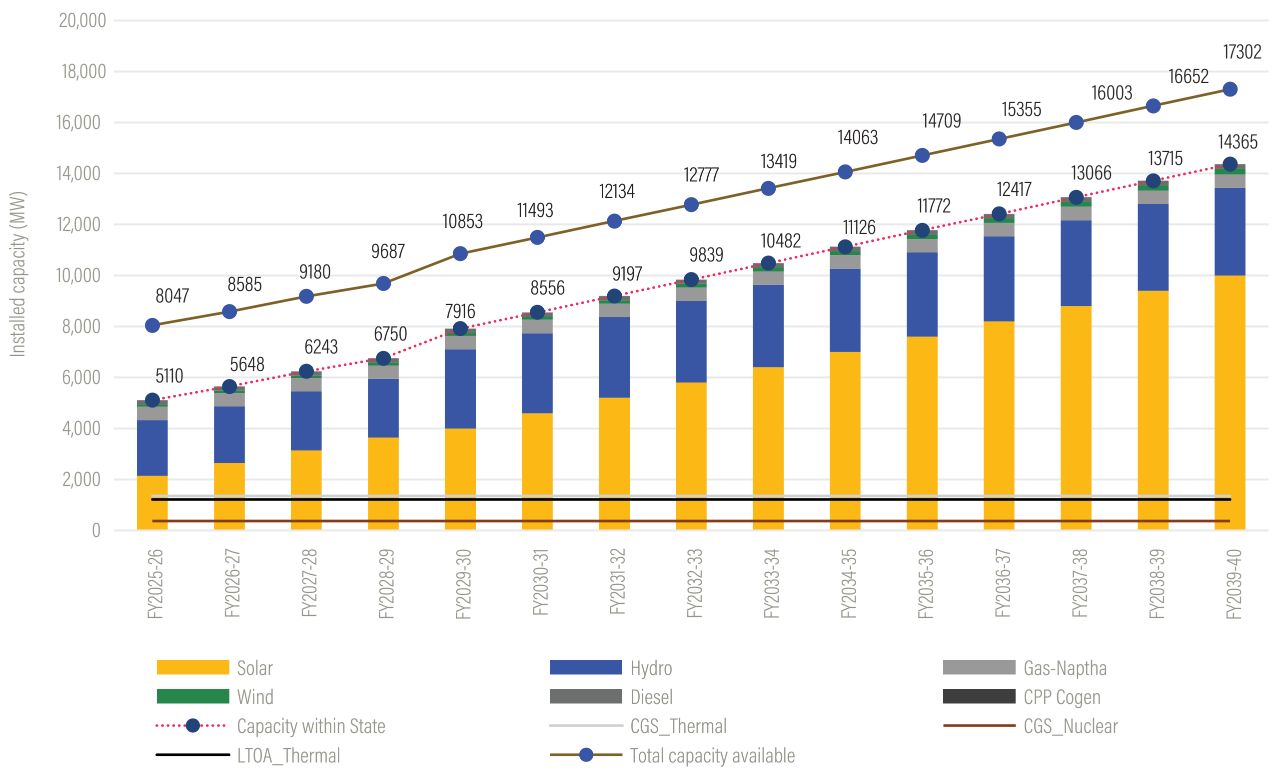
Appendix B. Sub-scenarios considered and related information

Figure B-1 | **Electricity procurement cost and savings: BAU scenario**



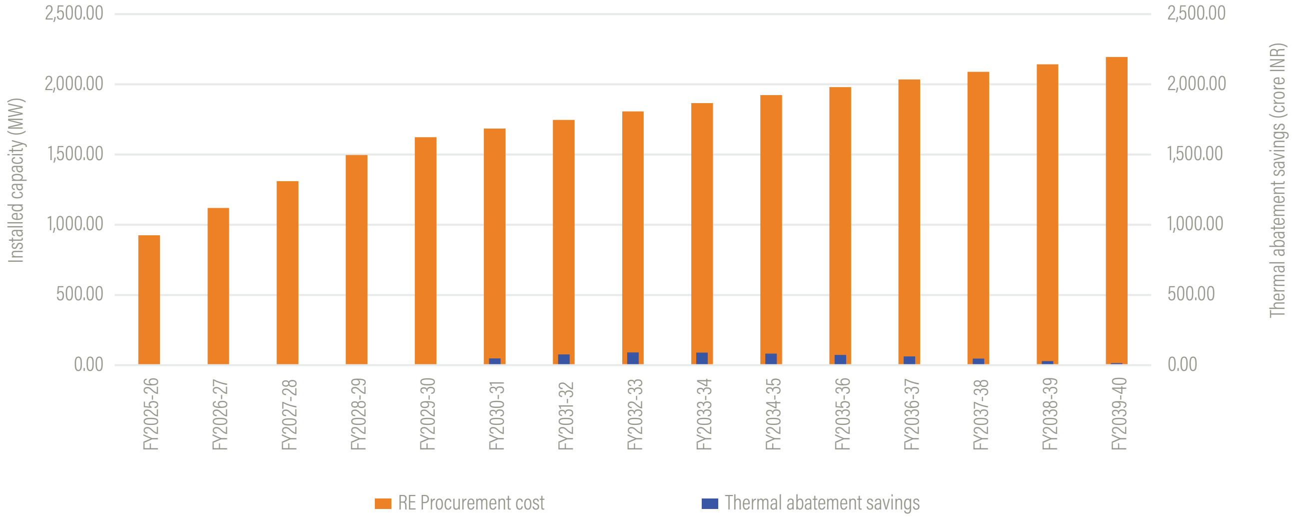
Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-2 | **Installed capacity growth estimate: High Renewables-High Solar sub-scenario**



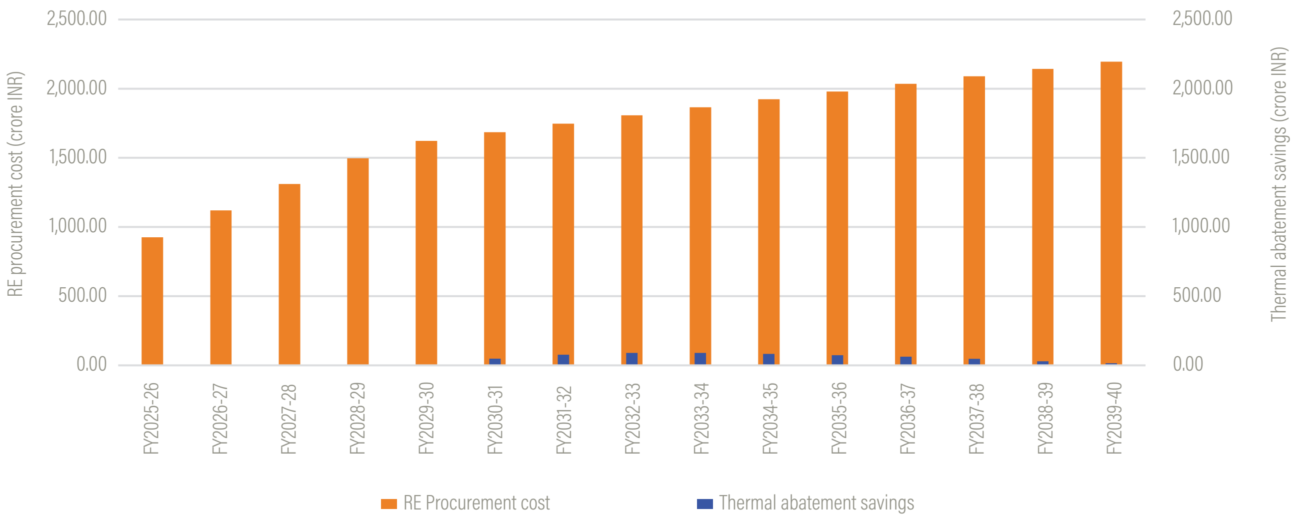
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MW = megawatt.
Source: WRI India authors.

Figure B-3 | **Electricity generation projections: High Renewables-High Solar sub-scenario**



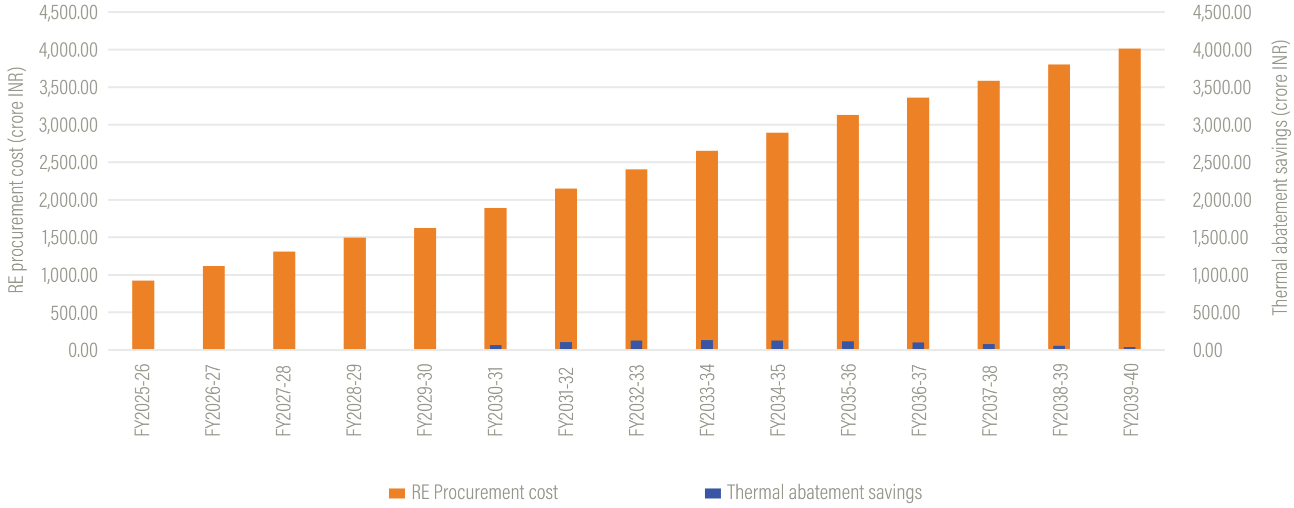
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MU = million units.
Source: WRI India authors.

Figure B-4 | **Electricity procurement cost and savings: High Renewables-High Solar sub-scenario**



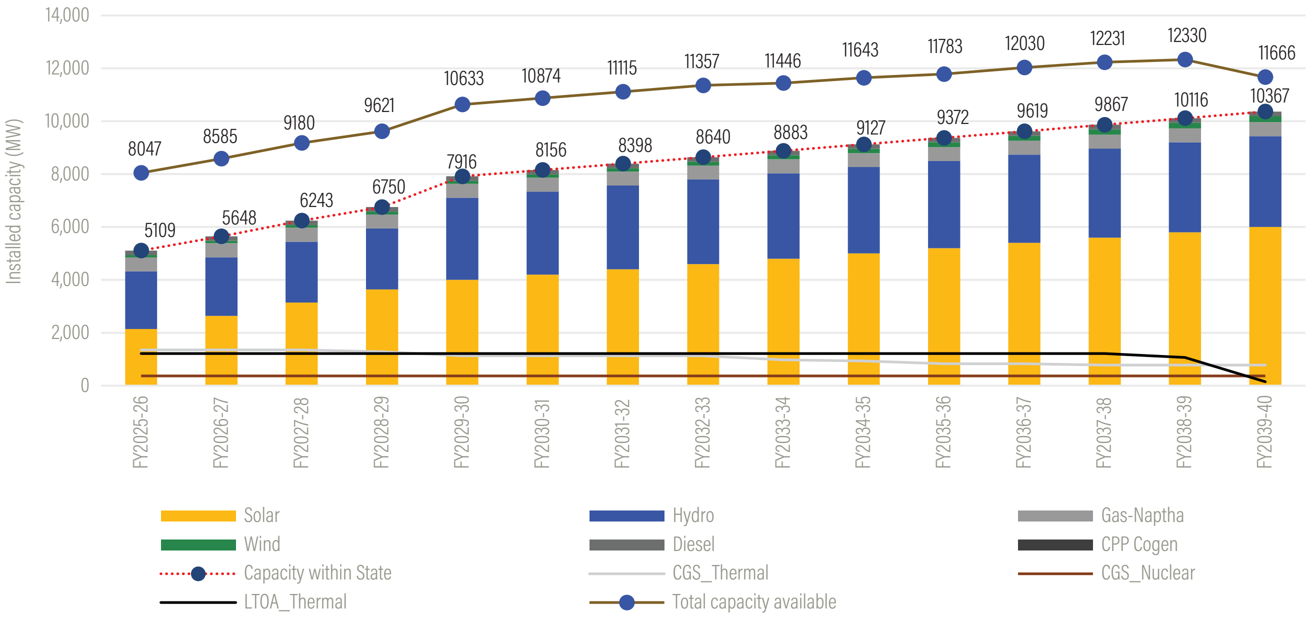
Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-5 | **Electricity procurement cost and savings: High Renewables-High Solar and Wind sub-scenario**



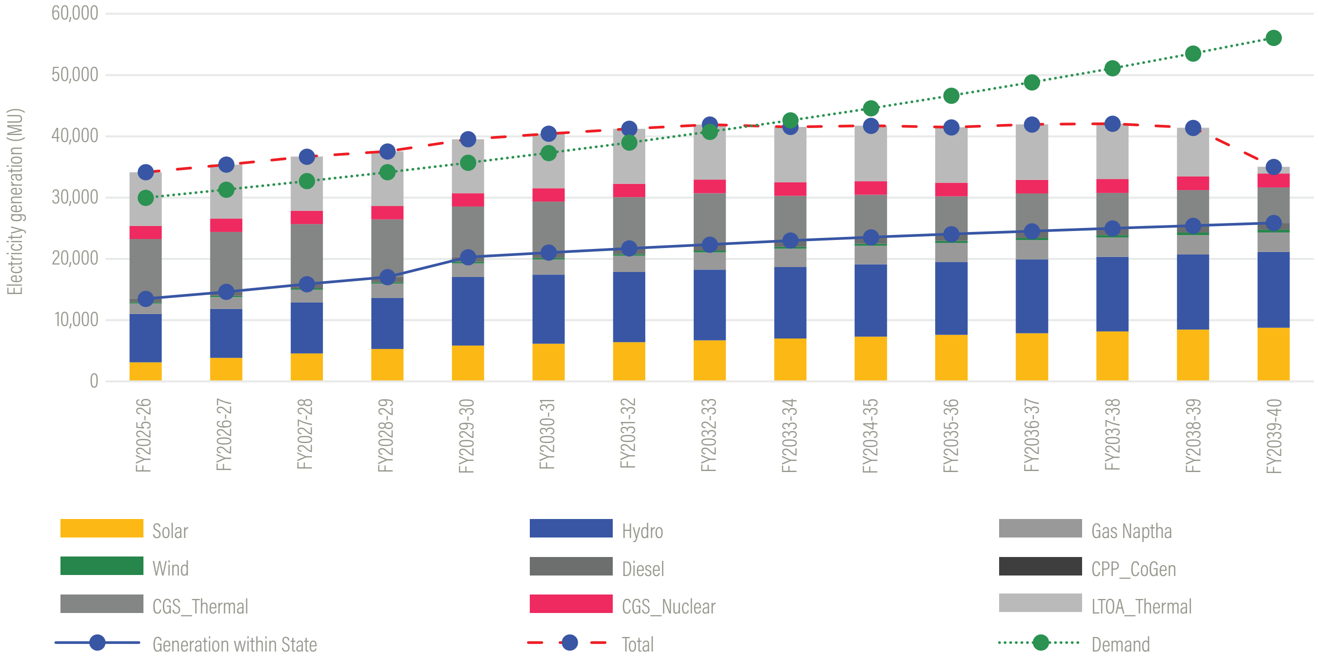
Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-6 | **Installed capacity growth estimate: Low Thermal (Nonrenewal of Expiring PPAs) scenario**



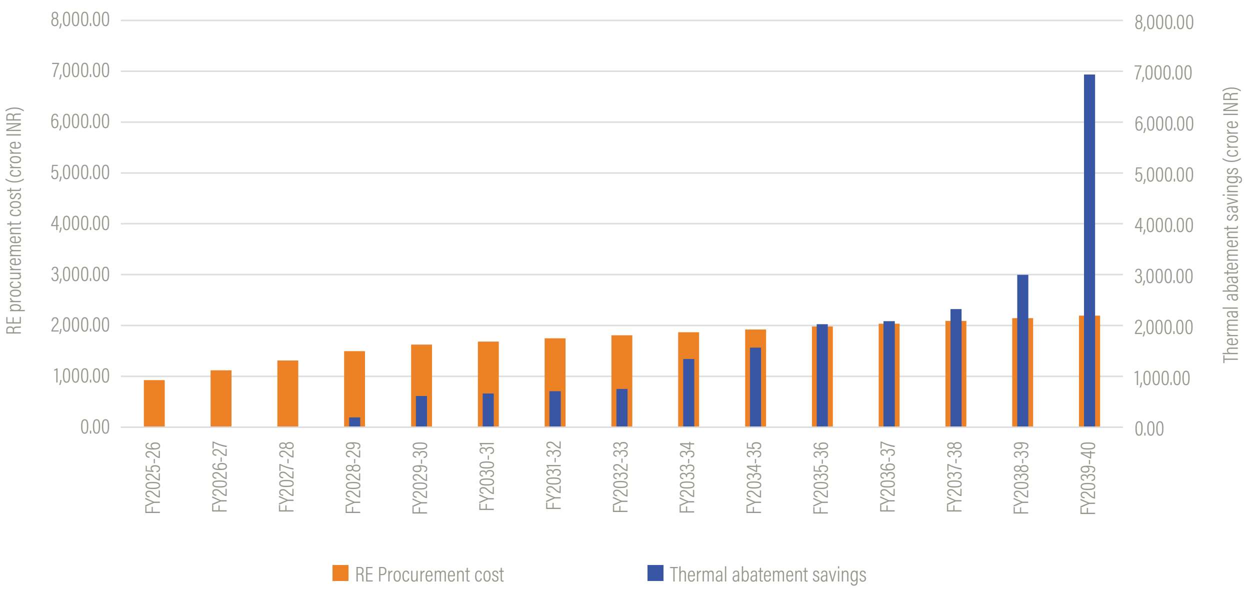
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MW = megawatt.
Source: WRI India authors.

Figure B-7 | **Electricity generation projections: Low Thermal (Nonrenewal of Expiring PPAs) scenario**



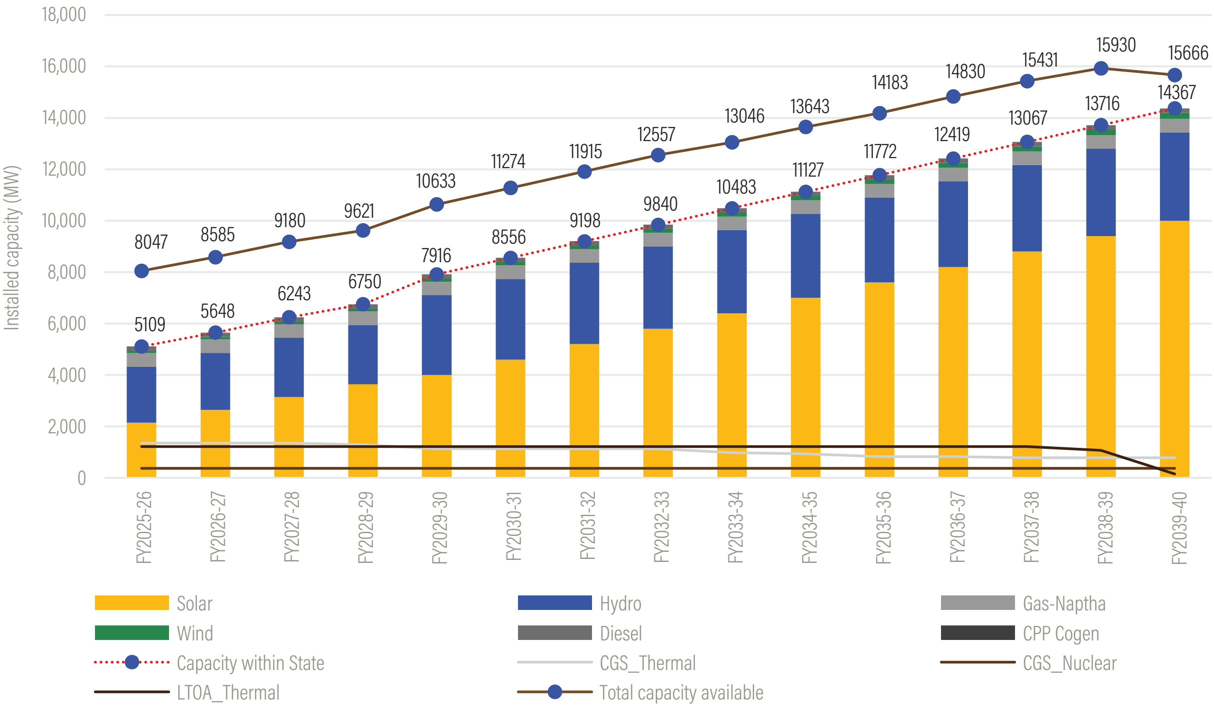
Note: CGS = central generating station. CPP = captive power producer. LTOA = long-term open access. MU = million units.
Source: WRI India authors.

Figure B-8 | **Electricity procurement cost and savings: Low Thermal (Nonrenewal of Expiring PPAs) scenario**



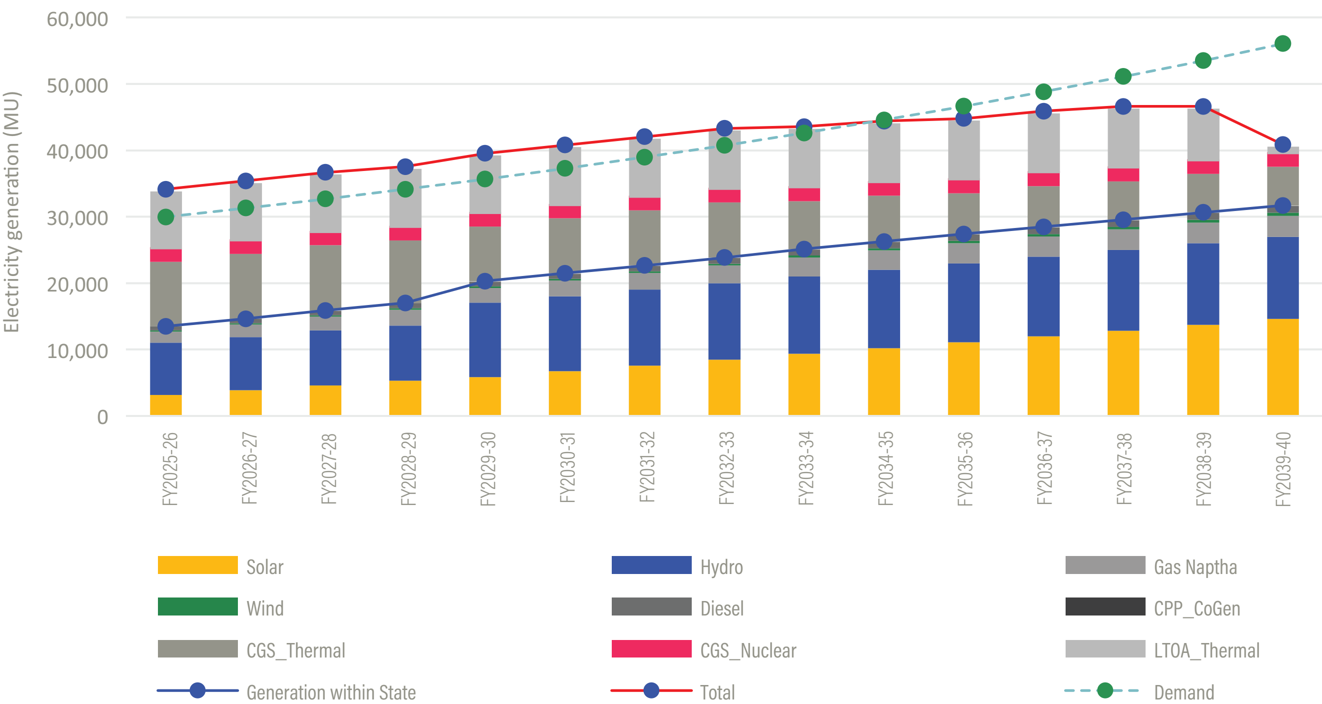
Note: INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-9 | Installed capacity growth estimate: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar) sub-scenario



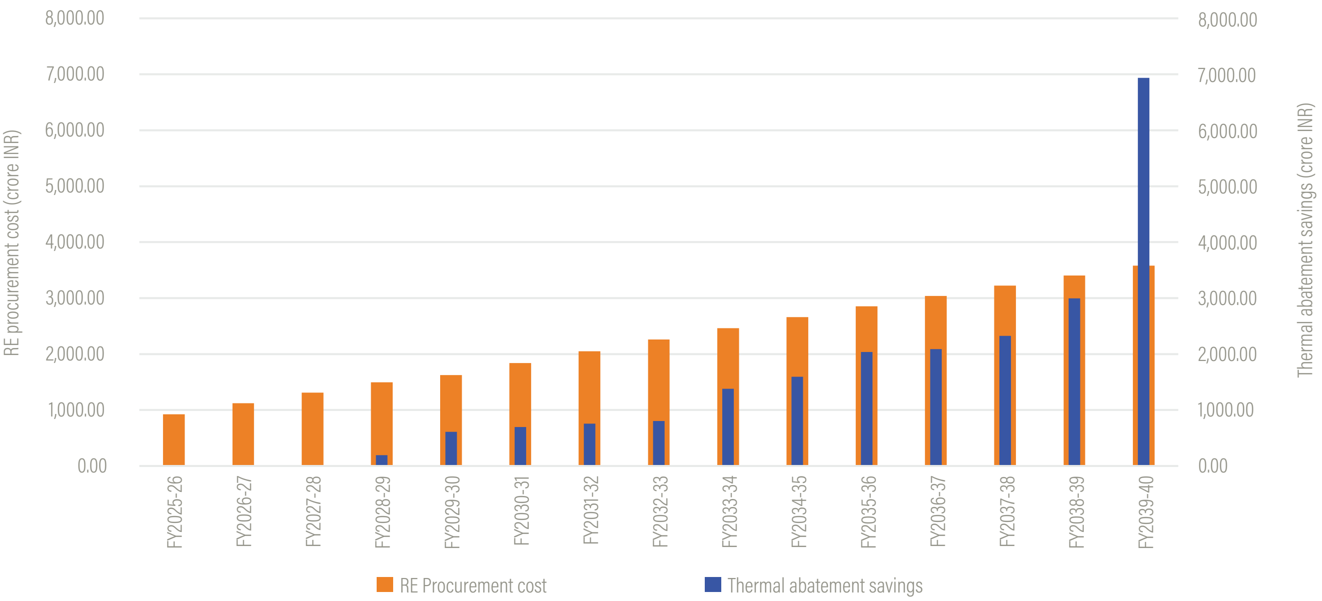
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MW = megawatt.
Source: WRI India authors.

Figure B-10 | Electricity generation projections: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar) sub-scenario



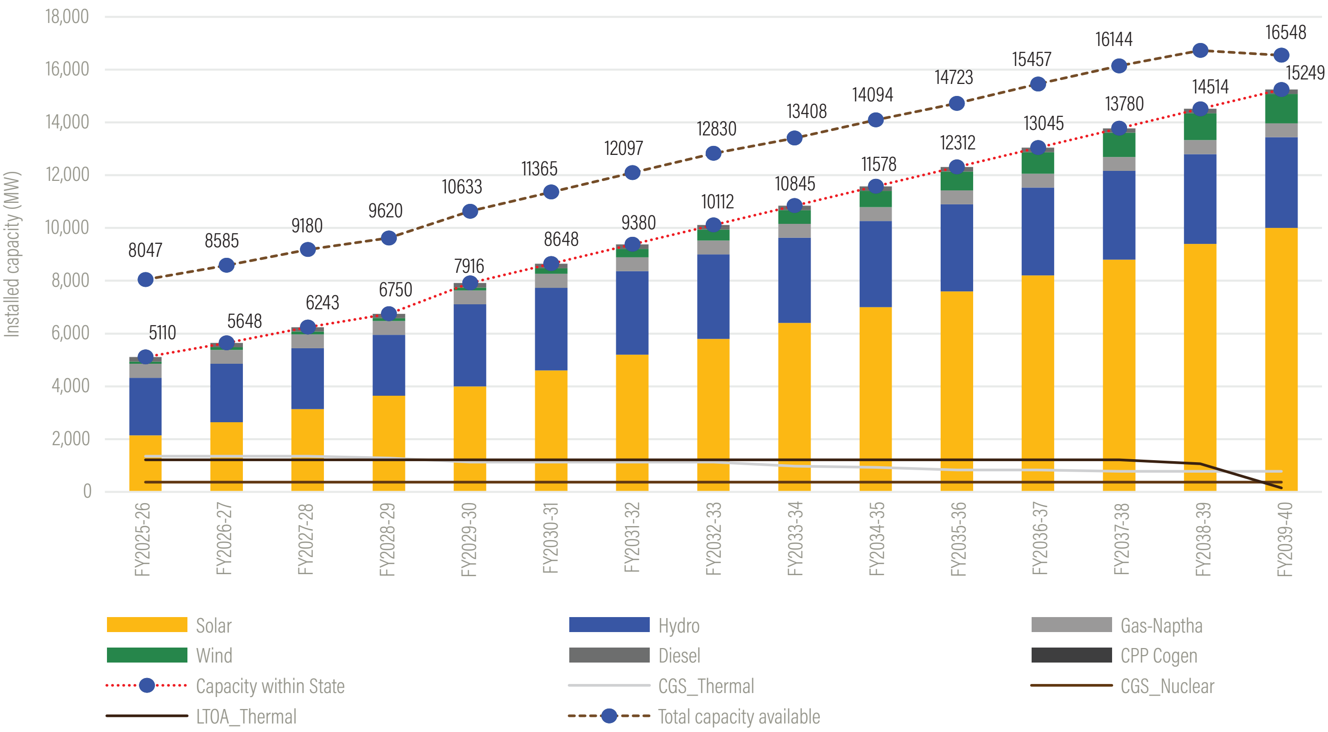
Note: CGS = central generating station. CPP = captive power producer. LTOA = long-term open access. MU = million units.
Source: WRI India authors.

Figure B-11 | **Electricity procurement cost and savings: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar) sub-scenario**



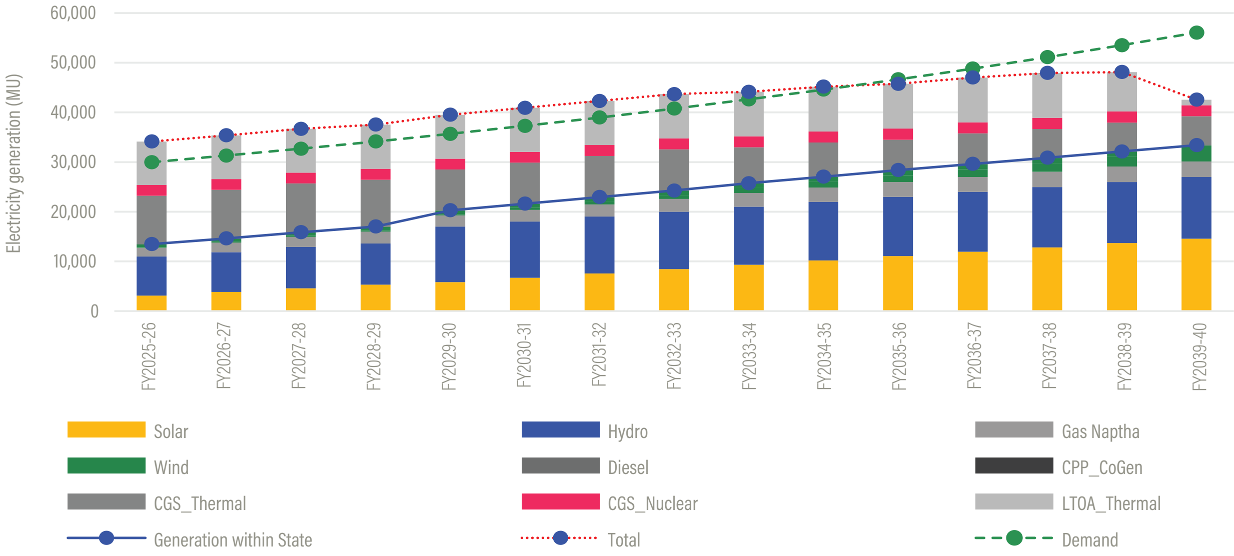
Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-12 | **Installed capacity growth estimate: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar + Wind) sub-scenario**



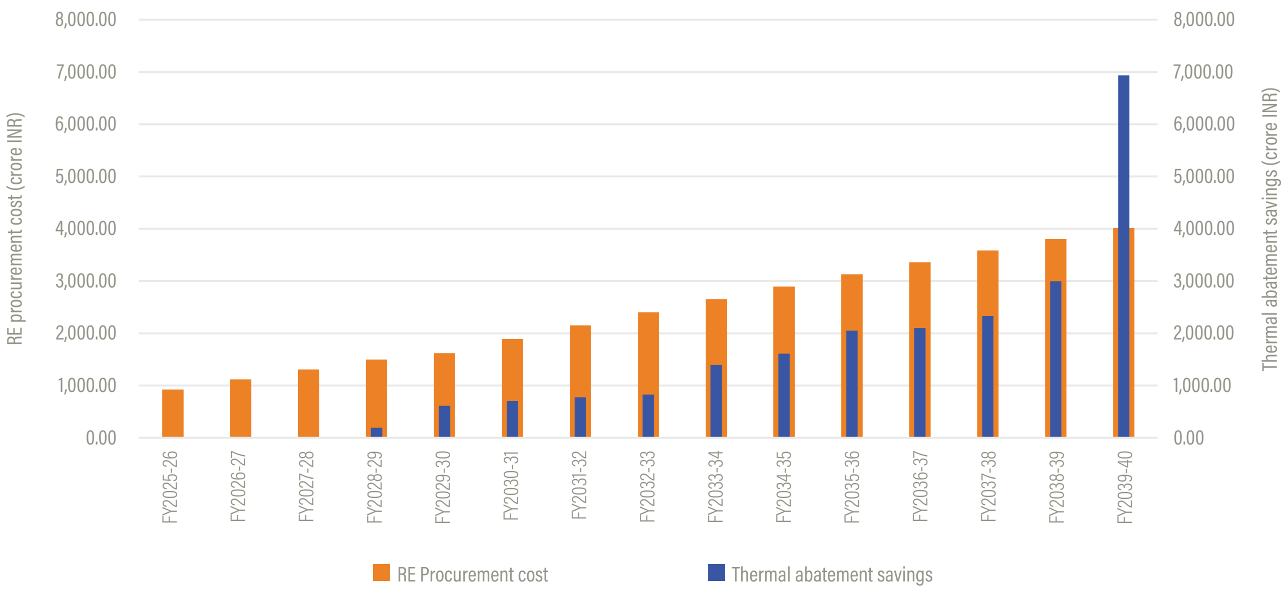
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MW = megawatt.
Source: WRI India authors.

Figure B-13 | **Electricity generation projections: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar + Wind) sub-scenario**



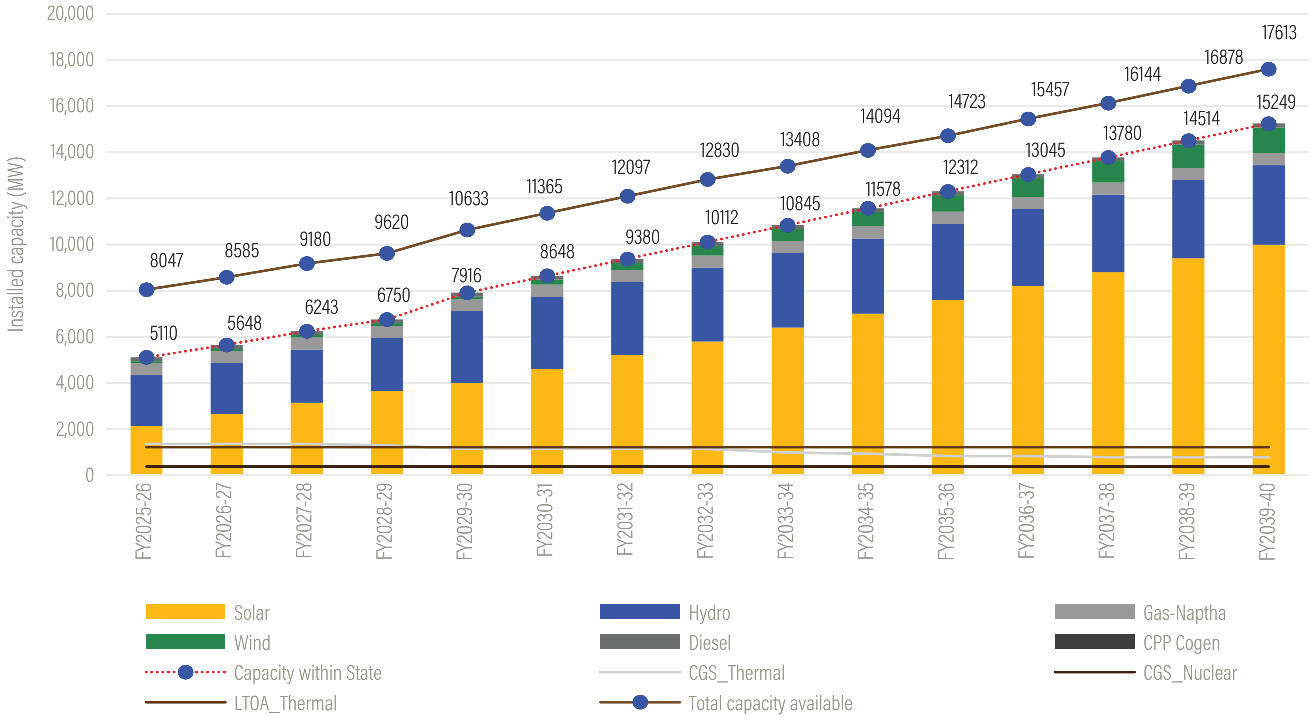
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MU = million units.
Source: WRI India authors.

Figure B-14 | **Electricity procurement cost and savings: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar + Wind) sub-scenario**



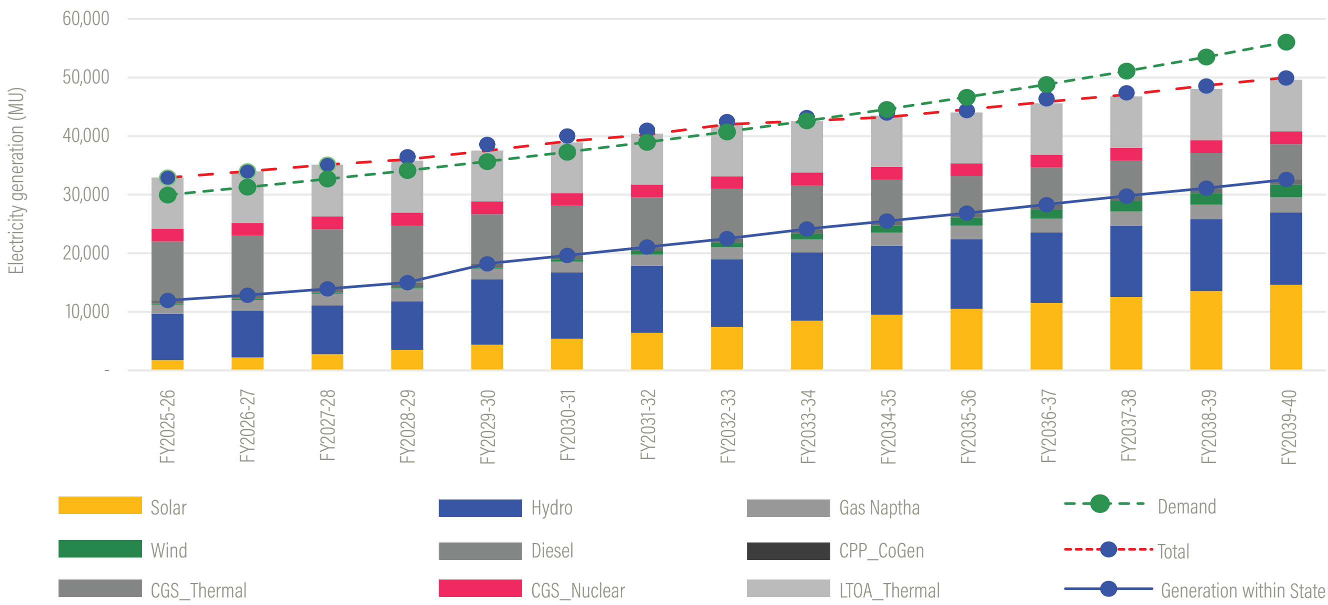
Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-15 | **Installed capacity growth estimate: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar + Wind + LTOA) sub-scenario**



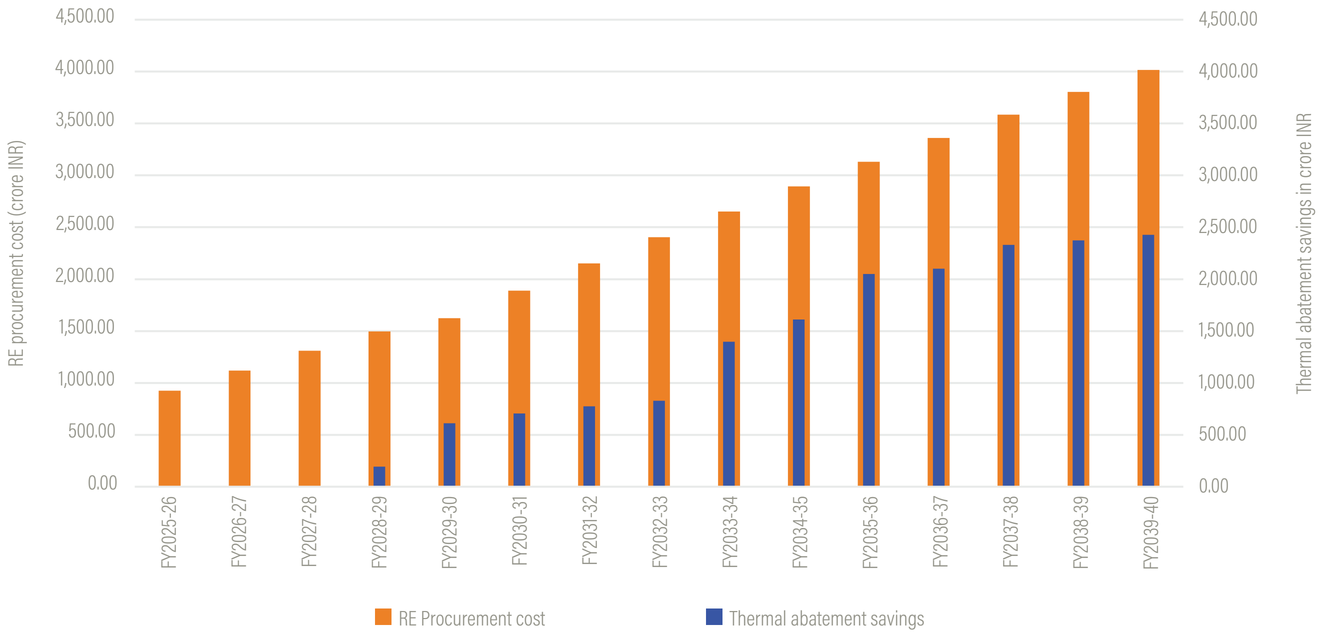
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MW = megawatt.
Source: WRI India authors.

Figure B-16 | **Electricity generation projections: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar + Wind + LTOA) sub-scenario**



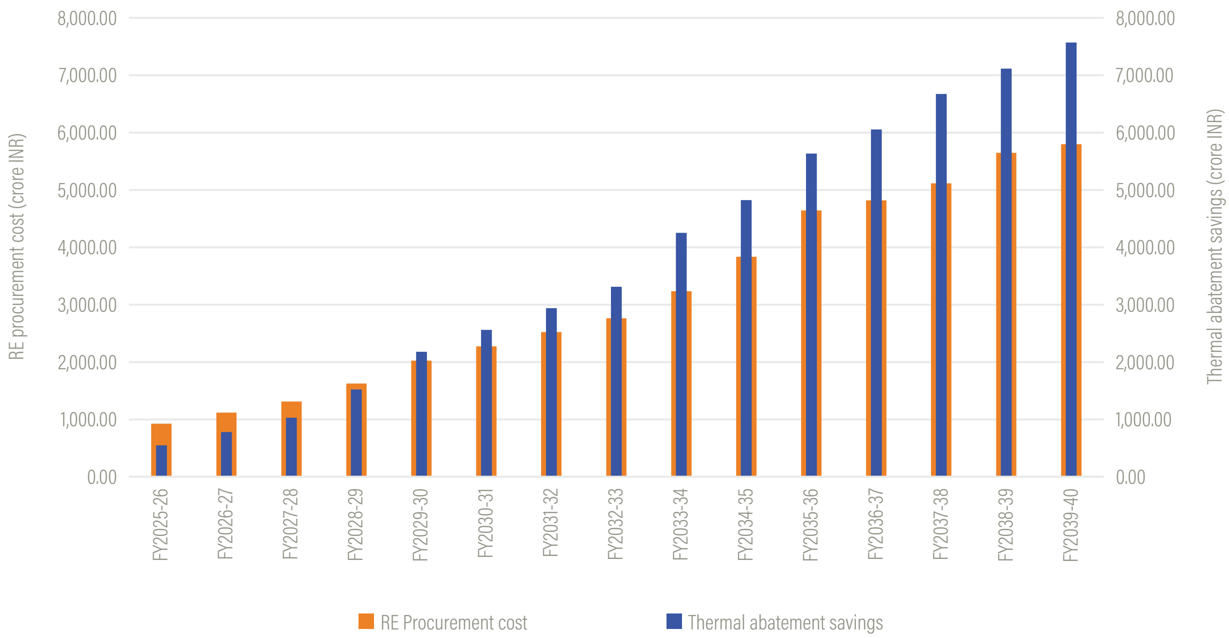
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MU = million units.
Source: WRI India authors.

Figure B-17 | **Electricity procurement cost and savings: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar + Wind + LTOA) sub-scenario**



Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-18 | **Electricity procurement cost and savings: Low Thermal (Nonrenewal of Expiring PPAs)-Compensating (Solar + Wind + LTOA + OA RE) sub-scenario**

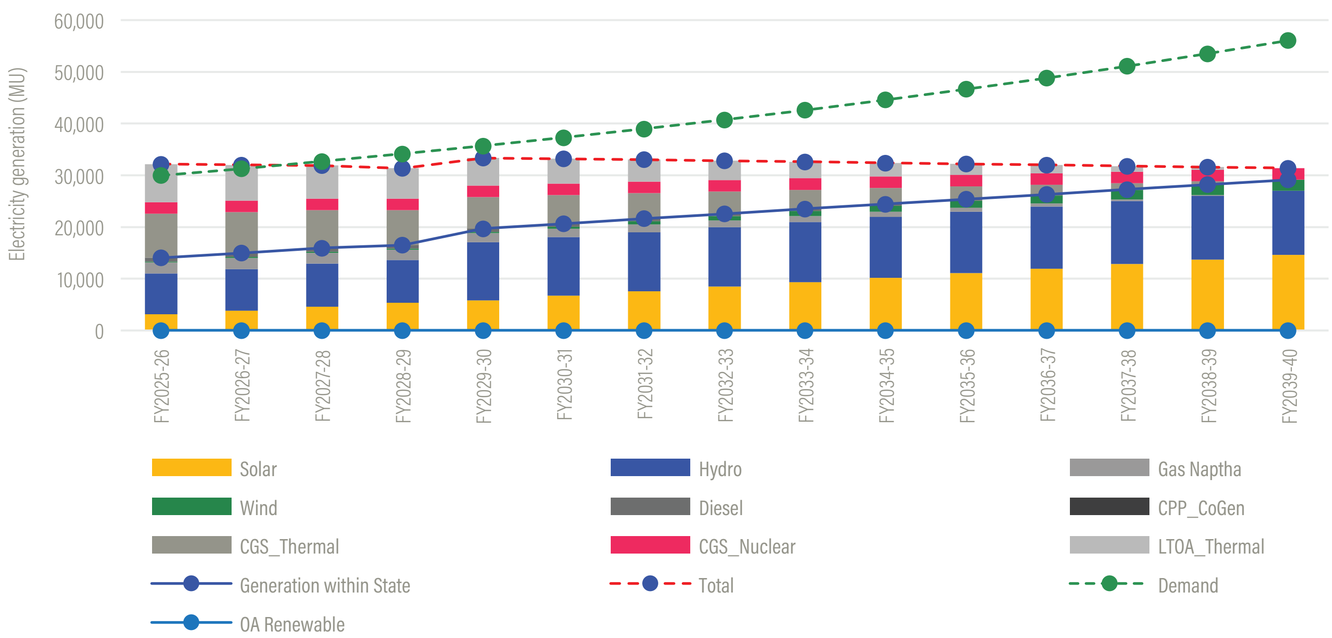


Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-19 | **Installed capacity growth estimate: Zero Thermal 2040 scenario**

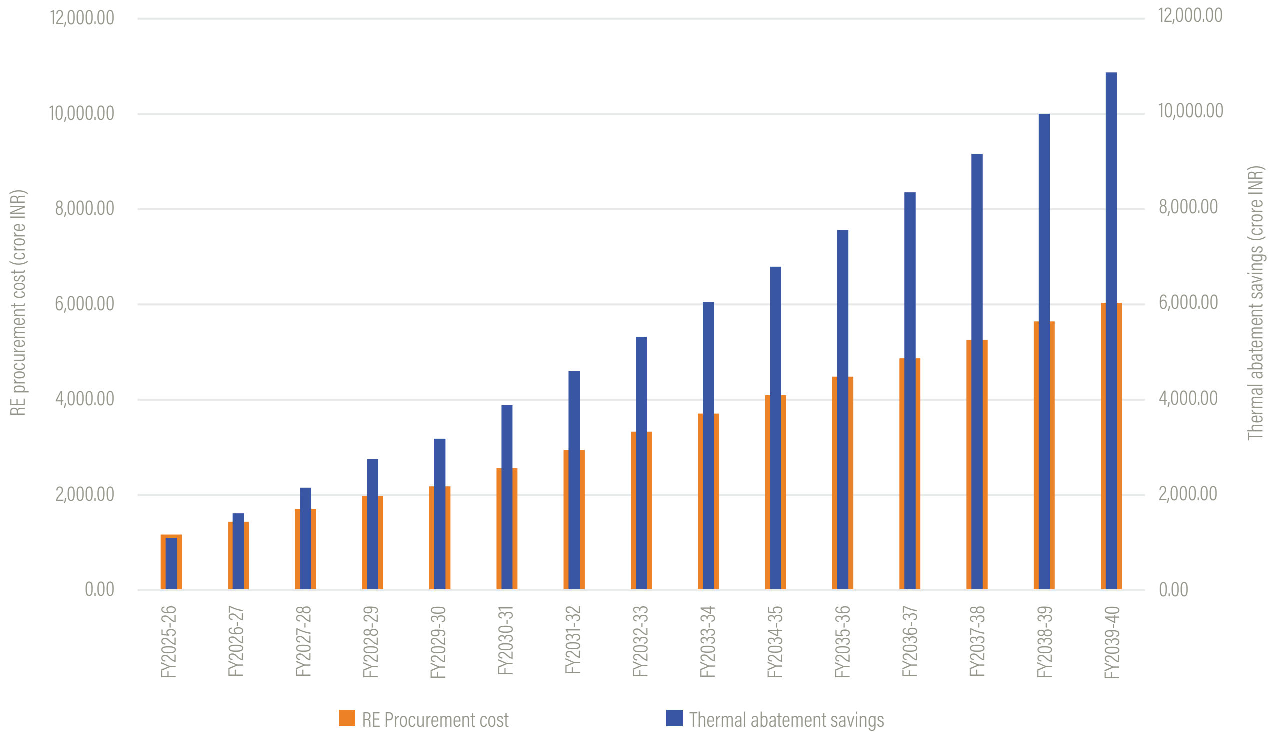
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MW = megawatt.
Source: WRI India authors.

Figure B-20 | **Electricity generation projections: Zero Thermal 2040 scenario**



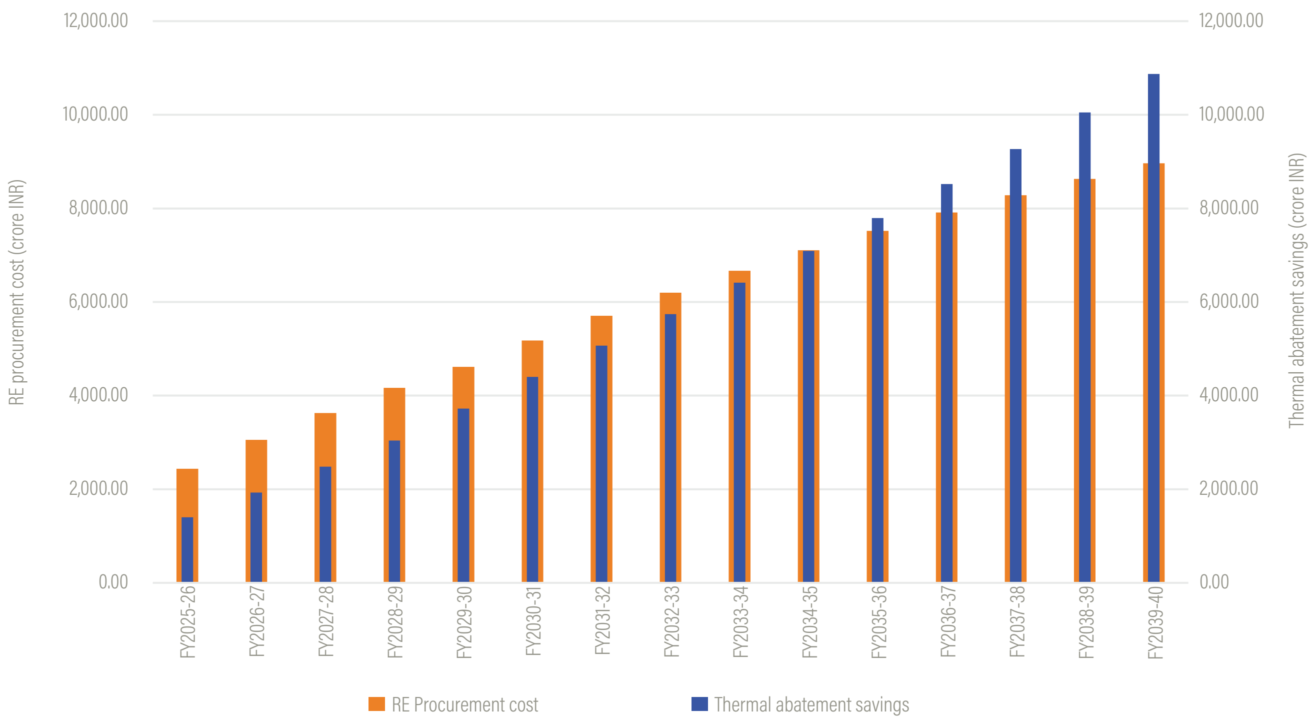
Note: CGS = central generating station. CPP = captive power producer. FY = fiscal year. LTOA = long-term open access. MU = million units.
Source: WRI India authors.

Figure B-21 | **Electricity procurement cost and savings: Zero Thermal 2040 scenario**



Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Figure B-22 | **Electricity procurement cost and savings: Zero Thermal 2040-Compensating (Balanced through RE Capacity Additions + OA RE) sub-scenario**



Note: FY = fiscal year. INR = Indian rupee. RE = renewable energy.
Source: WRI India authors.

Appendix C. Kerala's renewable potential, installed capacities, and challenges

Table C-1 presents the renewable technologies that can be considered for Kerala, along with information on their renewable potential, installed capacity, and so on, as discussed in Kumar et al. (2025).

Table C-1 | **Key aspects of suitable renewable technologies for Kerala**

RE TECHNOLOGY SUITABLE FOR KERALA	AVAILABLE POTENTIAL (MW)	CURRENT INSTALLED CAPACITY (MW)	KEY ASPECTS OF ITS ADOPTION
Wind (land-based, utility-scale)	2,311–2,621	70.27	■ Slow pace of capacity addition, historically. ■ Wind resource available in certain pockets, in high terrain areas. ■ Transportation of components to these locations is difficult. ■ Limited land availability and high cost of land acquisition.
Solar PV (land-based, RTS, FPV)	10,900	1,165	■ Utility-scale solar potential of 6,100 MW; FPV potential of 3,000–8,000 MW; combined potential of 10,900 MW. ■ Land availability is a challenge for large utility-scale installations, and decentralized options such as RTS will better suit the state.
Small hydro power	647.15	260	■ Obtaining environmental clearances causes project delays. ■ Project delays cause cost overruns.
Bioenergy	778.41	2.5	■ Bioenergy for electricity generation is not widely tapped in Kerala. ■ Bioenergy is harnessed through smaller decentralized biogas plants.
Ocean: Wave energy	4,900	0	■ Although high potential exists, there are no wave energy installations in Kerala. ■ Early stages of technology maturity and the associated high costs are challenges. ■ The first—and only pilot—wave energy project in India (150 kW) was set up at Vizhinjam in Thiruvananthapuram district of Kerala in the 1990s and decommissioned in 2011.

Note: FPV = floating photovoltaic. MW = megawatt. PV = photovoltaic. RE = renewable energy. RTS = rooftop solar.
Source: Kumar et al. 2025.

Appendix D. EV demand projections

Table D-1 | **EV demand projection for 2030**

USE CASE	VEHICLE TYPE	AVERAGE ANNUAL VEHICLE TRAVEL DISTANCE (KM)	VEHICLE EFFICIENCY (KWH/KM)	BAU (%)	CONSERVATIVE (%)	OPTIMISTIC (%)	EVS IN 2030 (BAU)	EVS IN 2030 (CONSERVATIVE)	EVS IN 2030 (OPTIMISTIC)	EV DEMAND 2030-BAU (MU)	EV DEMAND 2030-CONSERVATIVE (MU)	EV DEMAND 2030-OPTIMISTIC (MU)
Personal vehicles	Two-wheeler	1,0000	0.035	13	20	30	4,94,237	5,94,109	7,34,285	173	208	257
	Car (personal)	10000	0.15	6	10	30	89,655	1,14,478	2,34,583	134	172	352
Commercial passenger vehicles	Car (commercial)	52500	0.15	2	10	30	705	1,976	5,036	6	16	40
	Medium passenger vehicle	70000	0.6	0	1	5	0	40	212	0	2	9
Public transport vehicles	Three-wheeler autos	35000	0.05	15	20	30	30,430	34,612	42,484	53	61	74
	Public transport buses	70000	1	1	10	20	356	1,296	2,336	25	91	164
	E-rickshaw passenger	1,7500	0.08	0	0	0	769	769	769	1	1	1
Commercial Goods transport Vehicles	Light goods vehicle	35000	0.6	1	5	10	1,373	3,957	7,195	29	83	151
	Heavy Goods Vehicle	70,000	1.3	0	1	5	16	108	484	1	10	44
	Medium Goods Vehicle	70,000	1	0	1	5	0	38	204	0	3	14
	Three-wheeler goods	45,500	0.08	19	25	30	4,073	4,499	4,835	15	16	18
	E-rickshaw goods	17,500	0.07	100	100	100	1,126	1,126	1,126	1	1	1
Special cases	School bus	10000	1	0	5	10	0	246	495	0	2	5
	Ambulance	70000	0.6	0	1	5	0	10	67	0	0	3
	Tractor	5000	0.4	0	1	5	0	17	93	0	0	0
							6,22,740	**7,57,281**	**10,34,204**	**439**	**666**	**1133**

Note: BAU = Business-as-Usual. EV = electric vehicle. km = kilometer. kWh = kilowatt-hour. In the Indian numbering system, commas are used in a 3-2-2 pattern to group digits from the right: the first group of three digits separated by the first comma represents hundreds, and the subsequent two groups of two digits represent lakhs and crores, respectively. For example, 68,54,74,244 would be read as sixty-eight crore, fifty-four lakh, seventy-four thousand, two hundred and forty-four. 1 lakh = 100,000 and 1 crore = 10 million.

Source: KSEB 2025a.

Table D-2 | **EV demand projection for FY2029-30, FY2034-35, and FY2039-40**

NUMBER OF EVS REGISTERED IN KERALA				CATEGORY-WISE CAGR ASSUMED (%)			PROJECTED EV DEPLOYMENT IN KERALA				VEHICLE: CATEGORY-WISE DAILY ENERGY NEEDS			ANNUAL EV ENERGY DEMAND PROJECTION (MU)			
EV type	FY 2020–21	FY 2021–22	FY 2022–23	FY 2022–23 to FY 2029–30	FY 2020–31 to FY2034–35	FY 2035–36 to FY 39–40	FY 2024–25	FY 2029–30	FY 2034–35	FY 2039–40	Average daily run (km)	Energy consumption (kWh/km)	Daily individual energy need (kWh)	FY 2024–25	FY 2029–30	FY 2034–35	FY 2039–40
Two-wheeler	1,328	12,732	57,136	5	10	20	1,20,717	2,86,209	6,35,132	13,68,577	19.2	0.03	0.64	20.86	49.46	109.75	236.49
Three-wheeler	1,143	2,348	5,062	5	10	20	8,143	16,163	33,207	69,033	150	0.07	10	21.99	43.64	89.66	186.39
Four-wheeler	823	3,051	8,044	2	4	10	18,585	46,023	10,4338	2,57,550	27.2	0.14	3.89	19.5	48.28	109.47	270.21
Bus	13	13	63	2	4	10	225	646	1,540	3,890	90	1.25	112.5	6.83	19.61	46.78	118.17
Goods and commercial vehicles	2	2	2	0.40	1	5	315	1,129	3,293	14,661	150	0.8	120	10.2	36.59	106.68	475.02
Total	**3,309**	**18,146**	**70,307**				**1,47,985**	**3,50,169**	**7,77,510**	**17,13,711**				**79**	**198**	**462**	**1286**

Note: CAGR = compound annual growth rate. EV = electric vehicle. FY = fiscal year. MU = million units. In the Indian numbering system, commas are used in a 3-2-2 pattern to group digits from the right: the first group of three digits separated by the first comma represents hundreds, and the subsequent two groups of two digits represent lakhs and crores, respectively. For example, 68,54,74,244 would be read as sixty-eight crore, fifty-four lakh, seventy-four thousand, two hundred and forty-four. 1 lakh = 100,000 and 1 crore = 10 million.

Source: CSTEP 2024.

Appendix E. Descriptions of the designed scenarios

Scenario 1: BAU

The BAU scenario (i.e., the baseline scenario) is designed to reflect a situation that estimates changes in the future electricity supply-demand characteristics based on current policy targets, historical trends, and stakeholder inputs on the likely future capacity additions. This is necessary to understand what would likely happen in the future in the absence of any major interventions. We look at the historical capacity addition trends for the various electricity-generating sources available to Kerala, in conjunction with likely changes to these plans and capacity additions. We also calculate likely annual capacity additions for the power supply sources available in Kerala.

Solar: Being a relatively new entrant into Kerala's electricity landscape, using historical growth rates for predicting future capacities for solar would result in skewed data points. Kerala's solar policy of 2013 sets a target of 2,500 MW for 2030, and the RTS capacity addition target is 1 GW by 2030. Stakeholder discussions point to 300 MW/year of capacity additions of primarily solar photovoltaics (PVs) and point to a capacity of 4,000 MW by 2030. Accordingly, a value of 4,000 MW is used for 2030, which aligns with the state's solar potential. From 2030 to 2040, we consider 300 MW/year of capacity additions. The cumulative capacity in 2040 would be around 6 GW, which aligns with Kerala's likely achievable solar potential of about 9,500 MW. Hence, these numbers are used to model solar capacity growth for the BAU scenario.

Hydro: KSEB's capacity addition plans for hydro projects are considered, and the capacity additions included up to 2030 are largely based on its capital investment plan. This takes the 2030 hydro capacity to 3,105 MW. After this period, because no capacity addition plans are available in government documents, the capacity is incremented annually by a small growth rate of 1 percent, which is based on the historical growth rate observed from FY2012–13 to FY2021–22 and the available potential. This takes the capacity in 2040 to around 3,437 MW. In regard to Kerala's small hydro policy, a potential of 650 MW is identified in the state, the current capacity being 260 MW. The policy aims to tap as much of this potential as possible. Considering Kerala's untapped small hydro potential, a capacity increment of 390 MW is possible. Hence, establishing a capacity of around 3,450 MW by 2040 for the BAU scenario (with a large hydro growth rate of 1 percent or considering only the untapped small hydro potential) is a logical and achievable target.

Wind: For estimating capacity additions of wind energy, a growth rate of 7.3 percent from FY2012–13 to FY2022–23 is considered. This takes the 2030 capacity estimate to 115 MW and the 2040 capacity estimate to 231 MW. This represents around 10 percent of Kerala's currently identified wind potential from the 150 m (meter) hub height wind resource assessment (Kerala's 150 m wind potential is 2.6 GW) (NIWE 2023). This rate of growth for wind is practical because capacity additions for wind have been difficult in Kerala, and tenders for wind capacity additions have seen limited participation. Hence, more aggressive capacity addition may not be possible. The current 2030 and 2040 capacities would be practical and in line with historical growth rates.

Diesel, naphtha, thermal from other states: These capacities are retained without any additions because Kerala has no further capacity addition plans. Also, most of these sources are not currently utilized in the state.

Central generating station (CGS) share including thermal and nuclear/long-term open access (LTOA)/medium-term open access (MTOA): The share from CGSs is the allocated capacity of a central-government-owned power plant for Kerala. LTOA and MTOA are open access contracts signed by the state for the purchase of electricity from private power plants. For the case of Kerala, CGS and power plants under LTOA/MTOA contracts are located outside the state. The share from CGSs includes both thermal and nuclear capacity allocations, and the BAU scenario capacities have been retained. Note that when contracts expire, they are being renewed. In Kerala, signed CGS contracts have not lapsed but are observed to be renewed. Hence, this CGS capacity is retained. Renewal is also observed for LTOA/MTOA contracts; hence, their capacity is also retained.

Scenario 2: High Renewables

Here, we design a scenario wherein renewable capacity additions are planned at a higher rate than the BAU scenario, to the extent possible, based on Kerala's available renewable potential. This gives us an understanding of the future of Kerala's renewables landscape if interventions are made to harness the available renewable potential. This scenario considers accelerated capacity additions of solar and wind. Sub-scenarios are also modeled in which capacity addition is individually considered, first for solar alone and then for solar together with an increase in wind.

Under this scenario, Kerala's annual solar capacity additions are incremented by 700 MW/year from 2030 to 2040 to achieve a total solar installation of 10 GW by 2040. This is in line with Kerala's total available potential of around 10 GW (Kumar et al. 2025). The capacities of other sources such as wind, hydro, diesel, naphtha, and other state thermal and CGS/LTOA/MTOA shares are the same as in BAU. For the sub-scenario that also considers an increase in the capacity of wind, wind capacity is estimated to increase to 1,115 MW by 2040. This is about 40 percent of Kerala's estimated wind potential.

Scenario 3: Low Thermal (Nonrenewal of Expiring Thermal PPAs)

Even for the High Renewables–High Solar and Wind sub-scenario, it is observed that the share of thermal remains high in 2040. Hence, an exploratory scenario is modeled, which considers a reduction in thermal capacity. This is because Kerala targets 100 percent renewables by 2040 and the share of thermal remains high in the previous two scenarios.

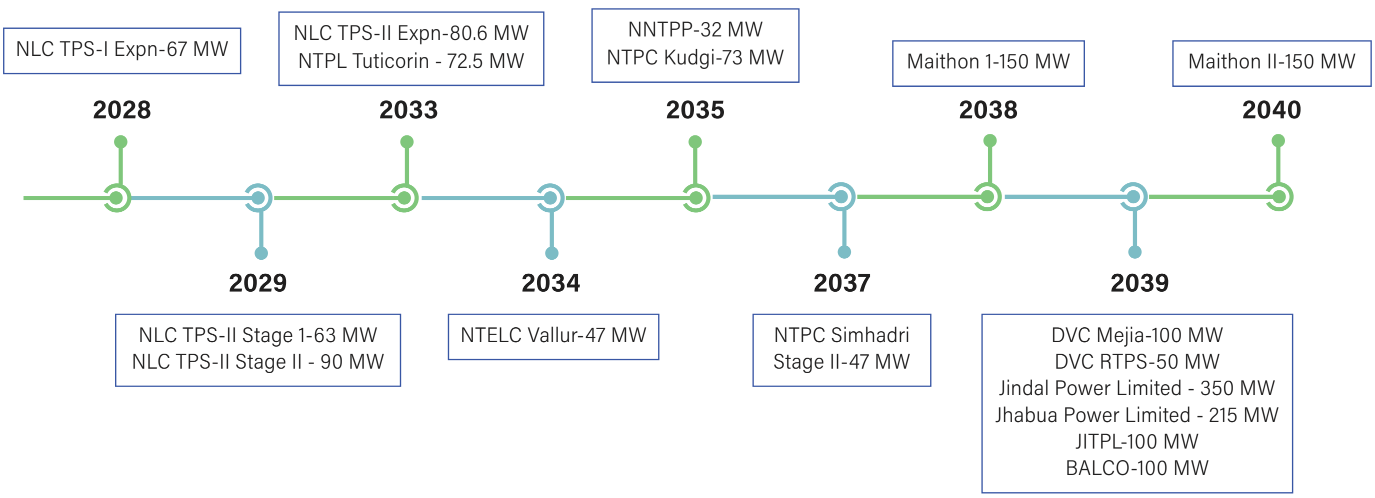
This scenario is modeled taking into consideration the high percentage of imported electricity from power purchase agreements (PPAs) that are primarily of thermal origin. For this scenario, it is assumed that the existing thermal PPAs are not renewed by the state upon their expiry. These are contracts from CGSs and power plants located outside Kerala (the economic implications of the nonrenewal of PPAs by Kerala for these power plants are not considered). Figure E-1 depicts the sequence of expiry of the existing PPAs. This intervention helps reduce the share of thermal electricity for this scenario.

However, considering that these power purchases are the major source of power in the BAU scenario, various options are considered to compensate for the reduction in capacity allocation and to meet the predicted demand. Various sub-scenarios as explored that compensate for the capacity loss through additions in solar; solar and wind; solar, wind, and LTOA; solar, wind, LTOA, and green energy open access. Open access contracts are considered renewable energy (RE) purchases by Kerala because additional renewable installations are precluded by the state's available potential.[3]

The first sub-scenario considers accelerated growth in solar alone, with 700 MW/year of capacity additions, while another sub-scenario considers accelerated capacity additions for both solar and wind: solar at 700 MW/year and wind capacity reaching 1,115 MW by 2040. Yet another sub-scenario is also modeled that retains the LTOA contracts, considering the presence of electricity shortfalls. However, electricity generation shortfalls are still observed for all of the above sub-scenarios.

To mitigate the shortfalls, another sub-scenario is created that compensates for the thermal capacity reduction with green energy open access contracts, which account for 440 MW by 2030 and 2,860 MW by 2040 in addition to the high rate of solar and wind capacity additions. Other supply sources are maintained per BAU. This is observed to mitigate shortfalls in electricity generation (see the section titled "Analysis and insights"). Also see Table 2 for a summary of the sub-scenarios.

Figure E-1 | **CGS and LTOA PPA expiry schedule**



Note: CGS = central generating station. LTOA = long-term open access. PPA = power purchase agreement.
Source: Fernandes and Sharma (2023) and the authors' research.

Scenario 4: Zero Thermal 2040

Overall, while modeling the above scenarios, it is observed that the share of thermal in Kerala's energy mix would still be around 13 percent by 2040, despite compensating for the nonrenewal of PPAs by adding renewable capacity additions and contracts. This scenario is created to estimate the renewable and non-thermal capacity allocations required for the state's thermal share to drop to zero by 2040.

This scenario considers a gradual annual reduction in thermal capacity (i.e., a reduction in the combined thermal capacity available to Kerala from CGS and open access contracts) so that it becomes zero by 2040. The reduction in thermal allocation is compensated by adding renewable capacity and renewable power purchase contracts.

In this scenario, solar and wind capacity is modeled per the High Renewables–High Solar and Wind sub-scenario, in which solar capacity increases at 700 MW/year from 2030 to 2040, reaching 10,000 MW by 2040, while wind capacity increases to 1,115 MW by 2040. Hydro capacity is per BAU. All thermal capacities are gradually reduced to 0 MW by 2040. Nuclear capacities are from CGSs (power imports); Kerala has no nuclear power plants. These capacities are retained per BAU. To address the shortfall in electricity supply, the reduction in thermal capacity is compensated by adding approximately 6,500 MW of renewable capacity by 2030 and 16,000 MW by 2040. We have not considered storage or mechanisms for short-term demand-supply management in this study. See Table 2 for a summary of these sub-scenarios.

Endnotes

1 The state also has intermediate target of meeting 50 percent of its energy targets from renewable sources by 2030.

2 The numbering system followed in this issue brief is the Indian numbering system. Typical values that are used are lakh (1 lakh = 100,000) and crore (1 crore = 10 million). Also, on average, the exchange rate in July 2026 was approximately US$1 = INR 96.02. Thus, INR 925 crore = approximately $96.33 million.

3 Renewable capacity additions required are beyond Kerala's available potential. In this case, no more installations are possible within the state and any allocation has to done through open access agreements with renewable power producers.

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