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CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

KERALA ENERGY TRANSITION ROADMAP 2040

Kerala Energy Transition Roadmap 2040

Center for Study of Science, Technology and Policy

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Designed and Edited by CSTEP

Disclaimer

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(The author list provided assumes no particular order as every individual contributed to the successful execution of the project.)

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Foreword

As we stand at this critical juncture in energy transition—where sustainability is no more an aspiration but a pressing need—Kerala has emerged as a frontrunner in charting a course towards a cleaner and more resilient energy future. The state's commitment to achieve net-zero emissions by 2050 and fulfil 100% of its energy requirements through renewable sources by 2040 is commendable.

To aid the state's efforts in this direction, the Center for Study of Science, Technology and Policy (CSTEP) conducted a comprehensive study, delving into the intricate dynamics of Kerala's energy landscape. This report presents a detailed analysis of the state's energy sector and provides a roadmap—informed by the study insights—outlining the initiatives, policies, and measures that can guide the state in moving towards a smooth energy transition, while also aligning with the renewable purchase obligations (RPOs) set by the Ministry of Power.

Considering the growing electricity demand, the intensifying climate change impacts, and the urgent need to reduce dependency on thermal imports, such a roadmap is indeed necessary and well-timed. I extend my appreciation to CSTEP and all the stakeholders involved in producing this important report, and hope that it will assist policymakers, industry stakeholders, and the people of Kerala in their collective endeavour to build a secure and sustainable energy future.

Dr R. Harikumar

Director

19 January 2024 — Energy Management Centre - Kerala

Executive Summary

The state of Kerala is committed to sustainability, with aims to attain net-zero emissions by 2050 and meet 100% of its energy requirements though renewable energy (RE) sources by 2040. However, currently the state's internal power generation meets only 30-35% of its energy requirements, while the rest is supplied by imports, predominantly sourced from coal-based resources. This scenario emphasises the need for understanding the state's energy dynamics and developing an actionable plan to reduce the dependence on thermal imports and enable a smooth RE transition.

In this context, the Center for Study of Science, Technology and Policy (CSTEP) conducted a study to devise an energy transition roadmap till financial year (FY) 2040 for the state. The roadmap will help the state in making informed decisions on RE transition—in compliance with the renewable purchase obligations (RPO) notified by the Ministry of Power (MoP)—to diversify its energy mix, reduce dependency on external sources, and build a more sustainable and resilient energy system.

Historically, the electricity demand in the state has grown at a compound annual growth rate (CAGR) of 3%, with the domestic category being the main driving factor. Based on the historic trends, we estimate that the state electricity demand would reach 40,446 MU by FY 2040 in a business-as-usual (BAU) scenario. We also assessed the impact of electric vehicles (EVs) and induction cooktop penetration on the state's BAU demand. We estimate that the penetration of 1.7 million EVs will increase the demand by 1,286 MU, while the usage of 1.2 million induction cooktops will add around 415 MU of energy demand by FY 2040. Thus, if the combined impact of EVs and induction cooktops is taken into account, the state would witness an increase of 1,701 MU in energy demand, accounting for 4% of BAU demand. The state's final energy demand, with transmission and distribution (T&D) losses, would increase from 26,821 MU in FY 2023 to 45,519 MU by FY 2040. Consequently, the peak demand is expected to increase to 7,594 MW by FY 2040 (from 4,374 MW in FY 2022).

To help the Kerala power sector in meeting the projected demand, while also aligning with its clean energy transition goals, we analysed two supply scenarios (BAU and high-RE) for the state, which entailed assessing the district-wise potential of solar and wind resources in the state. The assessment revealed that the total usable solar and wind potential in the state is approximately 14 GW. In the BAU scenario, we estimate that 8,391 MW of solar and 1,794 MW of wind capacity addition, along with the development of large- and small-hydro plants of 515 MW and 119 MW, respectively, will be needed by FY 2040. This will increase the share of RE in the energy mix from 4% in FY 2022 to 36% by FY 2040. Under the high-RE scenario, a phased reduction of thermal import is proposed on a year-on-year basis, leading to an addition of 10,558 MW of solar and 2,754 MW of wind capacity by FY 2040. Considering the need for grid flexibility, 1,056 MW of nuclear capacity would have to be added by FY 2040, along with large- and small-hydro capacity additions of 1,555 MW and 358 MW, respectively. Thus, the share of RE in the energy mix would increase from 4% in FY 2022 to 46% by FY 2040, whereas the thermal share would decrease from 56% to 2% and the nuclear share would increase from 6% to 19% during the same period, indicating a clear transition towards RE. It is important to note that this transition would need to be complemented by adequate energy storage systems. We estimate that the state would require 3.8 GW (7,163 GWh) of storage capacity addition in BAU scenario and 4.1 GW (8,108 GWh) in high-RE scenario.

On the basis of the above analysis and findings, the following recommendations have been made to enable Kerala to progress towards its renewable energy goals, while ensuring a reliable energy supply in the future:

- ***Enhance the uptake of decentralised energy resources through community-centric* rooftop photovoltaic *(RTPV) systems, green building programmes, and roof-leasing models.***
- ***Boost RE deployment through hybrid technologies (solar PV panels and vertical axis wind turbines).***
- ***Prepare comprehensive strategies for developing 4 GW of storage, including both pumped-hydro energy storage (PHES) and battery energy storage systems (BESS), with particular emphasis on managing peak demand and enhancing grid flexibility.***
- ***Initiate demand response programmes to monitor energy demand and reduce energy consumption across various categories through energy-efficiency measures.***
- ***Develop programmes that reward residents for adopting energy-efficient practices, such as reducing energy consumption during peak hours.***
- ***Introduce financial incentives, rebates, and subsidies for energy-efficient appliances and home upgrades.***
- ***Implement time-of-use tariff for EVs, as well as for residential consumers, to manage peak demand.***
- ***Develop an integrated platform to map the sales of EVs, tagging them to the consumer installation IDs, along with a single-window facility for EV consumers to apply for various benefits.***

It is crucial that Kerala acts fast to make use of the available RE potential, while also developing grid-flexibility mechanisms such as storage systems (BESS and PHES), so that the opportunities presented by high RE integration can be utilised. If the state plans to import RE power from the RE-rich states, appropriate policy advocacy for a smooth interstate transfer of RE power, along with strengthening and upgrading of inter-state transmission corridors, should be initiated.

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1. Introduction

As of March 2022, the total installed generation capacity[1] of Kerala stood at 5,956 MW. The installed capacity within the state is 3,145 MW, of which Kerala State Electricity Board (KSEB) owns the majority share of 2,259 MW (CEA, 2022). While hydro is a major source of energy generation, the state also relies heavily on thermal generation imports to meet the electricity demand of its consumers.

Kerala's commitment to sustainability reflects in its ambitious goals of attaining net-zero emissions by 2050 and meeting 100% of its energy requirements though renewable energy (RE) sources by 2040. Such targets underscore the need to understand the state's energy dynamics and come up with an actionable plan for a smooth RE transition.

In this context, the Center for Study of Science, Technology and Policy (CSTEP) conducted a study for developing an energy transition roadmap till 2040 to guide the state on crucial RE-transition decisions and enable it to foster sustainability and resilience in its energy system.

1.1 Objective

The objective of the study was to develop an actionable plan for facilitating Kerala's transition to clean energy (i.e., a higher RE share in its generation mix) by 2040, aligning with the state's commitment to strategically shift from traditional fossil-fuel-based energy sources to sustainable RE alternatives. As such, the study puts forth a roadmap with focussed recommendations to aid Kerala's efforts towards a smooth and sustainable energy transition by 2040.

[1] Includes installed as well as allocated share for the state of Kerala.

1.2 Methodology

For recommending measures for Kerala's clean energy transition, it was imperative to understand the state's future power demand and supply, and also the gap between the two. To forecast the electricity demand, we gathered historical data on electricity consumption for each consumer category over the past seven years (FY 16 to FY 22). This data was sourced from the Power System Statistics Report 2021-22, published by Kerala State Electricity Board (KSEB). We used the compound annual growth rate (CAGR) method to estimate the demand for each category up to FY 40. The assessment also factored in the impact of penetration of electric vehicles (EVs) and induction cooktops on the future energy demand.

To understand and plan for future supply, the projected energy demand for each year was compared with the energy supply available in the state in FY 22. The difference between these two represented the energy deficit for each year, which served as the basis for the year-on-year (Y-o-Y) estimation of energy supply and storage capacity from FY 23 to FY 40. For this, two supply scenarios were analysed—business-as-usual (BAU) scenario and high-RE scenario. Also, to understand the quantum of RE (particularly solar and wind) that can be used to cater to the projected demand, an RE potential assessment was carried out for the state to identify the implementable solar and wind potential through an in-house geographic information systems (GIS) tool, considering multiple criteria for decision-making.

Finally, the supply capacity required by the state to meet the projected demand, along with Y-o-Y storage requirements to manage the RE intermittency and provide round-the-clock power, was evaluated.

1.3 Structure of the Report

The report is divided into four main sections. The first section presents a brief overview of Kerala's power sector, specifically the progress made in all three sub-sectors (generation, transmission, and distribution) between FY 18 and FY 22. The second section estimates the annual energy requirements and peak-demand requirements for the state, Y-o-Y, till FY 40. The third section examines the Y-o-Y supply and storage requirements to meet the projected demand till FY 40, and the last section provides recommendations (for the generation and distribution sectors) based on the study analysis and findings, along with illustrative examples observed at a local or global level.

2. Kerala Power Sector Overview (2022)

The Electricity Act of 2003 marked a significant turning point for India's power sector by paving the way for states to unbundle their power sectors into separate entities on functional basis like generation, transmission, and distribution. However, Kerala's power sector continues to be handled in an integrated manner by the KSEB, which is responsible for power generation, transmission, and distribution activities in the state.

2.1 Generation Sector

The total installed generation capacity[2] of Kerala stood at 5,956 MW, as of March 2022 (Figure 1). The installed capacity within the state was 3,145 MW, with KSEB owning the majority share of 2,259 MW (CEA, 2022).

As for the fuel-wise breakup, thermal constitutes 52% of the total capacity, followed by hydro (31%), and nuclear energy (6%). The remaining 11% (671 MW) is contributed by solar, wind, small hydro, and other sources[3].

[2] Includes installed as well as allocated share for Kerala state

[3] BM Cogen (non-Bagasse) and waste-to-energy

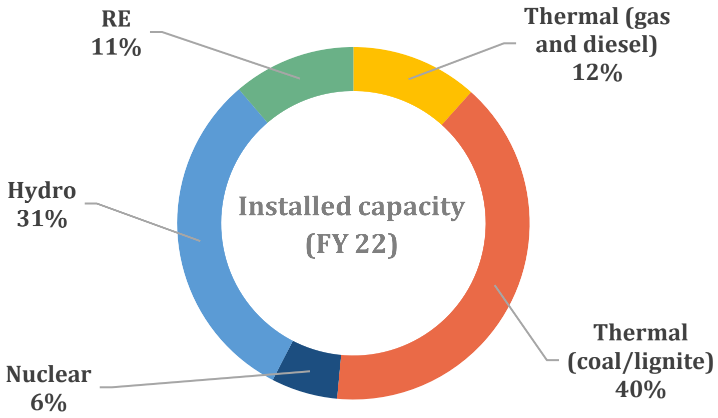


Figure 1: Installed capacity (FY 22)

Source: Central Electricity Authority (CEA)

In FY 22, 9,763 million units (MU) or 34% of the state energy demand was met by state-owned (KSEB) generation (KSEB, 2023), and the remaining 65% (18,888 MU) was sourced through imports from central generating stations (CGS) and private generators (Figure 2).

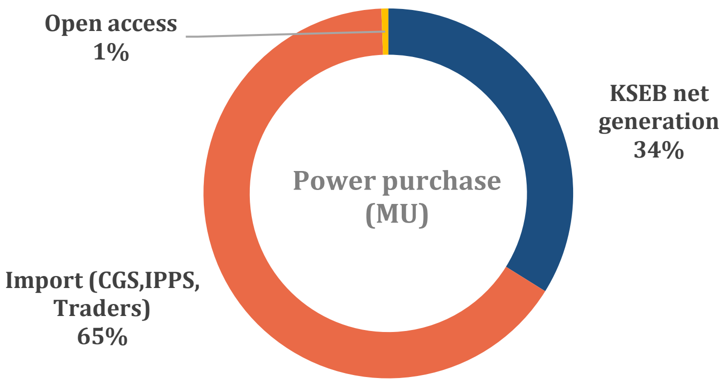


Figure 2: Source-wise power purchase for Kerala in FY 22 (in %)

Source: KSEB Power System Statistics 2021-22

The state witnesses high demand—both in terms of peak and energy requirements—during the months of March and April (Table 2 of the Appendix). Though the state was able to meet its energy requirement and peak demand with minimal shortfall between FY 18 and FY 22 (CEA, 2023), it is important to note that a significant portion of this was met through imports. This high dependence on external sources flags the need for developing self-reliance in Kerala's energy sector—poised for a transition to RE sources—to help it in becoming a net-zero state.

Table 1: Kerala's energy requirement and availability (from FY 18 to FY 22)

Financial Year	Energy Requirement (MU)	Energy Availability (MU)	Energy Not Supplied (MU)	Energy Not Supplied (%)
FY 18	25,004	24,916	88	0.4%
FY 19	25,016	24,898	118	0.5%
FY 20	26,315	26,265	50	0.2%
FY 21	25,118	25,102	16	0.1%
FY 22	26,612	26,605	7	0.0%

Source: Load Generation Balance Reports (LGBRs) by CEA

Table 2: Kerala's peak demand and availability (from FY 18 to FY 22)

Financial Year	Peak Demand (MW)	Peak Availability/Met (MW)	Demand Not Met (MW)	Demand Not Met (%)
FY 18	3,892	3,870	22	0.6%
FY 19	4,245	4,228	17	0.4%
FY 20	4,487	4,300	187	4.2%
FY 21	4,275	4,269	6	0.1%
FY 22	4,374	4,374	0	0.0%

Source: CEA LGBRs

2.2 Distribution Sector

A major share of electricity consumption in Kerala is attributed to the domestic category. In FY 22, the domestic category—comprising of 102 lakh consumers—accounted for 12,679 MU of electricity consumption. The industrial category (low tension [LT], high tension [HT] and extra high tension [EHT]), with only 1.07 lakh consumers, recorded a significant consumption totalling 5,937 MU, followed by the commercial category (with 25 lakh consumers) that accounted for a consumption of 3,310 MU. The agricultural category, with 5.1 lakh installations, consumed 374 MU of electricity. The remaining 1,200 MU of consumption is attributed to 'other' category that includes public lighting, railway traction, and licensees (KSEB, 2023).

Figure 3 depicts the historic trend in state electricity consumption between FY 18 and FY 22. From the figure, it can be inferred that the state did not experience a significant surge in demand during this period. However, a consistent growth pattern can be observed, primarily fuelled by domestic consumption.

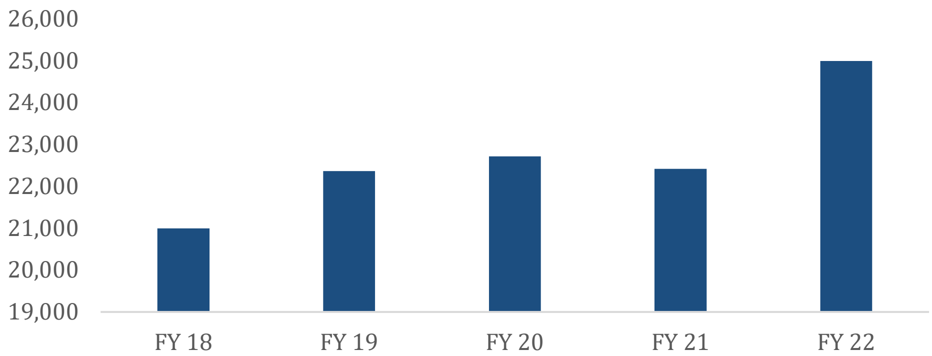


Figure 3: Kerala electricity consumption (in MU)

Source: KSEB Power System Statistics 2021-22

Overall, the total electricity consumption in Kerala for the FY 22 was 23,500 MU, covering a diverse range of consumers across different categories[4].

[4] Others include railway traction, licensees, and public lighting.

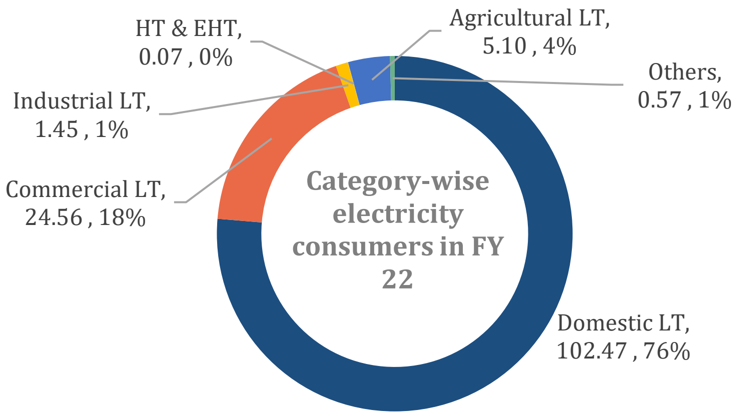


Figure 4: Category-wise electricity consumers in FY 22 (in lakh)

Source: KSEB Power System Statistics 2021-22

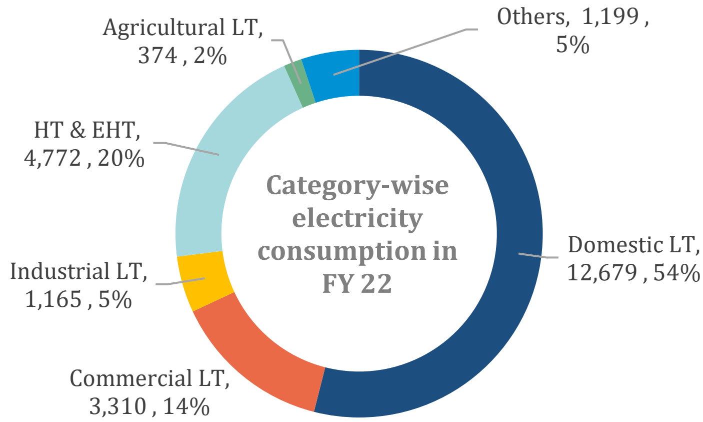


Figure 5: Category-wise electricity consumption in FY 22 (MU and percentage)

Source: KSEB Power System Statistics 2021-22

The state's transmission and distribution (T&D) losses have reduced significantly—from 13.07% in FY 18 to 10.19% by FY 22—as shown in Figure 6.

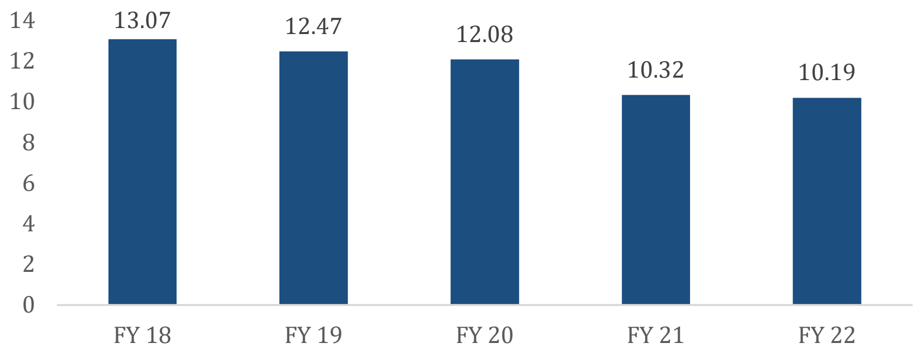


Figure 6: T&D losses (%)

Source: KSEB Power System Statistics 2021-22

The renewable purchase obligation (RPO) targets for the state are set by the Kerala State Electricity Regulatory Commission (KSERC), while the Agency for New and Renewable Energy Research and Technology (ANERT) is designated as the state agency for RPO. Table 3 depicts the Y-o-Y achievements against the solar and non-solar RPO targets.

Table 3: Kerala's RPO (from FY 18 to FY 22)

Financial Year	Solar		Non-Solar	
	Target	Achievement	Target	Achievement
FY 18	1.50%	0.81%	6.00%	4.84%
FY 19	2.75%	1.28%	7.00%	5.24%
FY 20	4.00%	1.47%	8.00%	4.10%
FY 21	5.25%	2.61%	9.00%	5.59%
FY 22	6.75%	4.07%	10.25%	9.38%

Source: KSEB Power System Statistics 2021-22

KSEB has made progress in meeting the RPO targets for both solar and non-solar categories over the years. However, there is still a gap between the RPO targets and the actual achievements, indicating that there is room for improvement (for consistently meeting the set targets).

In addition, the state needs to look into the RPO and energy storage obligation trajectory notified by the Ministry of Power (MoP), Government of India (GoI), on 22 July 2022 for the period from FY 23 to FY 30 (MoP, 2022a).

To bridge the gap and ensure consistency in the achievement of RPO targets, KSEB may need to focus on exploring the state RE potential and implement strategies for increasing RE procurement and curtailing thermal power purchase for building a more sustainable and environment-friendly energy sector in Kerala.

Kerala's internal power generation meets only 30-35% of its energy requirements and the rest is primarily supplied by imports, predominantly sourced from coal-based resources. This high dependence on imports highlights the need to explore more RE resources, in compliance with the state's RPO targets, to diversify its energy mix, reduce dependency on thermal sources, and tap the entire RE potential of the state for fostering a sustainable and resilient energy system.

3. Demand Projections: FY 23 to FY 40

For Kerala, accurate demand forecasting (DF) is crucial to efficiently plan and manage its operations, including energy procurement, peak-demand management, and revenue forecasting. We projected the state's energy demand from FY 23 to FY 40 Y-o-Y, by analysing the historical consumption trends and evaluating how the penetration of EVs and induction cooktops would influence the future demand.

3.1 CAGR-Based BAU Demand Forecasting Model

For the model, we used the CAGR method to estimate the demand for each category within the state. The model used a constant rate of Y-o-Y growth (based on past trends) to estimate the energy demand. Table 4 presents the historic category-wise sales consumption in the state.

Table 4: Historic category-wise energy consumption (in MU)

Category	FY 16	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22	CAGR (%)
Domestic LT	9,944	10,281	10,575	10,864	11,898	12,700	12,679	4%
Commercial LT	2,735	2,958	3,063	3,221	3,426	2,982	3,310	3%
Industrial LT	1,103	1,132	1,112	1,112	1,085	1,087	1,165	1%
HT & EHT	4,106	4,128	4,536	4,724	4,616	3,955	4,772	2%
Public Lighting	367	376	373	378	366	377	363	0.5%
Agricultural LT	279	322	346	338	348	403	374	4%
Licensees	578	612	609	597	616	496	507	1%
Railway Traction	213	230	266	303	305	151	330	6%
Total	**19,325**	**20,038**	**20,881**	**21,537**	**22,661**	**22,152**	**23,500**	**3%**

Source: KSEB Power System Statistics 2021-22

With the above growth rates, the category-wise BAU demand without T&D losses was estimated Y-o-Y up to FY 40.

Table 5: Consumer-category-wise projected electricity demand (in MU)

Category	FY 23	FY 25	FY 30	FY 35	FY 40
Domestic	13,127	14,071	16,739	19,913	23,688
Commercial-LT	3,401	3,592	4,116	4,716	5,404
Industrial-LT	1,174	1,193	1,240	1,290	1,341
HT-EHT	4,875	5,089	5,665	6,307	7,021
Public Lighting	379	382	391	400	410
Railway Traction	351	398	544	744	1,017
Licensees	624	639	681	725	773
Agricultural LT	390	424	522	643	792
BAU Demand (MU)	**24,321**	**25,788**	**29,899**	**34,378**	**40,446**

Our analysis shows that the overall energy consumption in the state is growing at a CAGR of 3%. By FY 40, the domestic category is expected to make up 59% of the total energy consumption, indicating the significant role of households and residential sectors. The industrial sector—both LT and HT categories—is projected to account for 21% of the state's energy consumption.

3.2 Impact of EV and Induction Cooktop Penetration on Future Energy Demand

In Kerala, EVs have been gaining traction as a sustainable and eco-friendly transportation alternative. The state government has been actively promoting EV adoption through various initiatives and policies. Similarly, induction cooktops have gained popularity in recent years in the state (Harikumar, 2017). Through discussions and consultations with EMC officials, we conducted an analysis to understand the impact of the growing uptake of EVs and induction cooktops on the state's energy demand in the coming years.

Electric vehicles

In 2019, the state came up with the Kerala State EV Policy that aimed to deploy 1 million EVs by 2022 (Transport Department, Kerala, 2019). Currently, the deployment of EVs is observed across all vehicle categories. According to the data from Vahan Dashboard (MORTH, 2023), in FY 23, the total number of registered EVs in the state was 70,307. Of these, the two-wheeler fleet has the highest share (81%), followed by four-wheelers (11%), and three-wheelers (7%).

Table 6: Number of EVs registered in Kerala

EV Type	FY 21	FY 22	FY 23
2W	1,328	12,732	57,136
3W	1,143	2,348	5,062
4W	823	3,051	8,044
Buses	13	13	63
Goods and Commercial Vehicles	2	2	2
Total	**3,309**	**18,146**	**70,307**

Source: Vahan Dashboard

Kerala has witnessed a significant surge in EV deployment, with the number of EVs almost quadrupling from 18,146 in FY 22 to 70,307 in FY 23 (Table 6). For estimating the number of EVs deployed by FY 40, we employed a phased approach that takes into account the CAGR for different vehicle categories over time intervals. Table 7 depicts the CAGR assumed for each vehicle category.

Table 7: Category-wise CAGR assumed

EV Type	FY 23 to FY 30	FY 31 to FY 35	FY 36 to FY 40
2W	5%	10%	20%
3W	5%	10%	20%
4W	2%	4%	10%
Buses	2%	4%	10%
Goods and Commercial Vehicles	0.4%	1%	5%

The approach enabled us to assess the growth of EVs in a structured manner, taking into account the specific trends in each category. If the state considers the above CAGR, it would be able to achieve its target of 1 million EVs by FY 36. Table 8 depicts the projected EV deployment.

Table 8: Projected EV deployment in Kerala

EV Type	FY 25	FY 30	FY 35	FY 40
2W	1,20,717	2,86,209	6,35,132	13,68,577
3W	8,143	16,163	33,207	69,033
4W	18,585	46,023	1,04,338	2,57,550
Buses	225	646	1,540	3,890
Goods and Commercial Vehicles	315	1,129	3,293	14,661
Total	**1,47,985**	**3,50,169**	**7,77,510**	**17,13,711**

We estimated the energy demand for charging each type of EV, considering the respective energy consumption and daily kilometres travelled, as shown in Table 9.

Table 9: Vehicle-category-wise daily energy needs

EV Type	Average Daily Run (km)	Energy Consumption (kWh/km)	Daily Individual Energy Need (kWh)
2W	19.2	0.03	0.64
3W	150	0.07	10.00
4W	27.2	0.14	3.89
Buses	90	1.25	112.50
Goods and Commercial Vehicles	150	0.80	120.00

Table 10 presents the Y-o-Y annual energy demand for the projected number of EVs. **We estimate that by FY 40, EVs would constitute 5.9% of the total vehicles registered in state, with an energy demand of 1,286 MU (accounting for 3.2% of the overall energy demand in the state).**

Table 10: Annual EV energy demand projection (in MU)

EV Type	FY 25	FY 30	FY 35	FY 40
2W	20.86	49.46	109.75	236.49
3W	21.99	43.64	89.66	186.39
4W	19.50	48.28	109.47	270.21
Buses	6.83	19.61	46.78	118.17
Goods and Commercial Vehicles	10.20	36.59	106.68	475.02
Total EV demand	**79**	**198**	**462**	**1,286**
% share of EV demand within BAU demand	**0.3%**	**0.7%**	**1.3%**	**3.2%**

Induction cooktops

The Kerala Consumer Segmentation Study conducted in 2015-16 focussed on clean fuel and cook stoves in Kerala (Nielsen India, 2016). Around 3,929 households were surveyed across eight districts in the state, of which 9.2% (360 households) reported using induction stoves, primarily for fast cooking, such as making tea, and boiling water and milk. Further, the India Residential Energy Survey (IRES) conducted in 2020 (Agrawal et al., 2020) revealed that around 12.5% of the 384 household sampled under the IRES in Kerala use electric cooking appliances.

For the analysis, we assumed that up to FY 30, the penetration rate of induction cooktops would stand at 12% for households at the state level, and this would increase at the rate of 0.2% Y-o-Y from FY 31 to FY 40.

The number of domestic consumer installation (households) has grown at a CAGR of 2% from FY 13 to FY 22. However, the Y-o-Y growth rate has decreased from 2.51% in FY 14 to 1.69% in FY 22.

On the basis of projections made in a report[5] by the Ministry of Health and Family Welfare (MoHFW, 2020) regarding Kerala's population growth up to 2035, we assumed that a decline in population growth would also decrease the growth rate of domestic consumers in the coming years. Therefore, to project the number of domestic consumers, we considered a 0.06% reduction[6] Y-o-Y from FY 23 to FY 30, and a 0.02% reduction from FY 31 to FY 40.

Table 11: Energy demand projection for induction cooktops (in MU)

Particulars	FY 23	FY 25	FY 30	FY 35	FY 40
Penetration rate[7] (%)	12%	12%	12%	13.0%	14.0%
No. of households (lakh)	102.46	107.57	116.65	126.50	137.19
Addition of induction cooktops (lakh)[8]	0.20	0.61	1.70	4.14	6.91
Energy demand (MU)[9]	**12**	**36**	**102**	**249**	**415**

We estimate the energy demand from the use of 10.20 lakh induction cooktops to be around 415 MU by FY 40.

The BAU demand forecast was overlaid with the impact of EV and induction cooktop penetration to arrive at the final demand forecast.

Table 12: Final Y-o-Y energy DF (in MU)

Particulars	FY 23	FY 25	FY 30	FY 35	FY 40
BAU Demand	**24,321**	**25,788**	**29,899**	**34,378**	**40,446**
EVs	34	79	198	462	1,286
Induction Cooktops	12	36	102	249	415
Final Demand (without T&D losses)	**24,367**	**25,904**	**30,199**	**35,450**	**42,147**
T&D Loss Trajectory (%)	*10.07%*	*9.83%*	*9.23%*	*8.62%*	*8.00%*
Final Demand (with T&D losses)	**26,821**	**28,451**	**32,986**	**38,505**	**45,519**

[5] As per the "Population Projections for India and States 2011–2036" report by MoHFW, the projected population growth rate of Kerala during the period 2021-25 is 4%; this would decline to 2.7% and 1.4%, respectively, during 2026-2030 and 2031-35. In addition, the net migration rate up to FY 35 would be -0.03 and -0.08 for males and females, respectively, indicating that the emigrants would outnumber the immigrants for the state.

[6]The reduction rate of 0.06% has been derived by averaging the FY 21 and FY 22 reduction rates of domestic consumers. Further, we assumed that domestic consumer growth will stabilise at 0.02%.

[7]Base year penetration rate (12.5%) has been considered till FY 30 and an increment of 0.2% has been considered thereafter to reach 14% penetration rate by FY 40.

[8]The induction cooktops in FY 22 (numbering 12.29 lakh) have not been considered as their demand is already captured under domestic category.

[9]Considering the average use of induction cooktops as 2 kW for 1 hour a day.

The state has demonstrated commendable progress in reducing its T&D losses on an annual basis, and we expect this positive trend to continue. We estimate that the current T&D losses of 10.2% in FY 22 will steadily decline to 8% by FY 40, with an annual reduction rate of 0.15%.

Upon considering the impact of EVs and induction cooktops, the state would see an increase of 1,701 MU in energy demand, accounting for 4% of BAU demand. The final energy demand (with T&D losses) would increase from 26,821 MU in FY 23 to 45,519 MU by FY 40.

Table 13 depicts the estimated peak and off-peak demand for the state, considering the final demand with T&D losses. **We estimate that the peak demand would increase from 4,374 MW in FY 22 to 7,594 MW by FY 40.**

Table 13: Projected peak and off-peak demand (in MW)

Financial Year	Peak Demand (MW)	Off-Peak Demand (MW)
FY 22	4,374	1,825
FY 23	4,474	1,867
FY 25	4,746	1,981
FY 30	5,503	2,297
FY 35	6,423	2,681
FY 40	**7,594**	**3,169**

Our analysis shows that Kerala's BAU energy requirement will grow at a CAGR of 3% to reach 40,446 MU by FY 40. The EVs and induction cooktops demand will further increase the BAU demand to 42,147 MU. On considering the T&D losses, the final energy requirement for the state would stand at 45,519 MU by FY 40.

4. Demand-Supply Planning: FY 23 to FY 40

This section first briefly discusses the assessment of Kerala's RE potential, and then details a supply-planning strategy for the state from FY 23 to FY 40, considering various factors that impact its energy mix. The primary focus of this strategy is to meet the state's projected demand through an energy mix that has a higher share of RE sources. We also analyse the deployment of energy storage systems to balance the grid during peak-demand instances and periods of high RE generation.

4.1 Assessment of Kerala's RE Potential

For evaluating the state's ability to meet the forecasted energy demand through RE sources, an assessment of the state's RE potential was conducted. The CSTEP team[10] assessed the district-wise potential of solar and wind sources in the state by employing the geographic information system (GIS), considering multiple criteria. Areas with higher solar radiation, lower average temperatures, and lower average relative humidity were deemed more favourable for siting solar-photovoltaics (PV) systems. Land characteristics such as high elevation, southward direction slope, flatter or gentle slope (less than 5°), and wasteland or bare ground were also identified as appropriate for solar-PV system placement. The importance of cost-effectiveness was also acknowledged, and proximity to power substations, major roads, and residential areas was considered advantageous for solar-PV system siting. A similar approach was followed for assessing the wind potential, and factors such as wind power density, land cover, distance to substations, biodiversity hotspots, etc., in the state were analysed. Following the assessment,

[10] CSTEP has an in-house expert team for assessing RE potential through GIS.

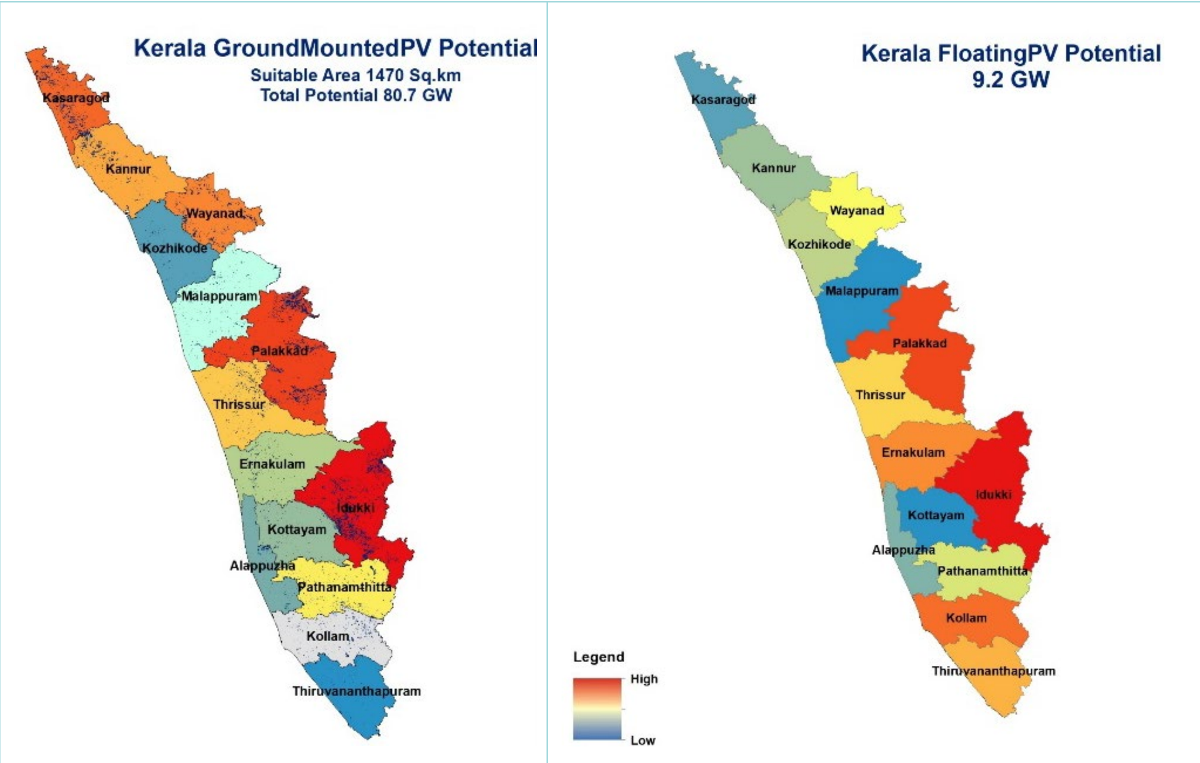
suitable land areas meeting these criteria were identified and the associated potential was evaluated.

Solar potential

For this assessment, we considered 1470 sq. km of land with a potential of around 80.7 GW for ground-mounted solar plants. However, as MNRE allows using only 3% of the wastelands (NISE, 2022)**,** the ground-mounted solar potential of Kerala stands at 2,423 MW. The districts of Idukki, Palakkad, and Kasargod (highlighted in red in Figure 7) have the highest potential. Additionally, Kerala's Agri-PV potential is estimated to be 4,000 MW. The assessment of floating solar- PV potential focussed on identifying perennial water bodies with an area greater than 0.015 sq. km, ensuring minimum ecological disruption. The overall potential of FPV in the state is 9.2 GW, of which 10% (920 MW) can be utilised. Idukki has the highest FPV potential in the state. We estimated the canal-top solar-PV potential in the state to be 3,600 MW, with Alappuzha district having the highest potential. **The total useable solar potential in the state is 10,953 MW** (Figure 7).

Wind potential

The area suitable for deployment of wind plants is around 272 sq. km, with a wind potential of around 2,993 MW**.** Idukki, Palakkad, Thrissur, and Wayanad districts have the highest potential (Figure 8).



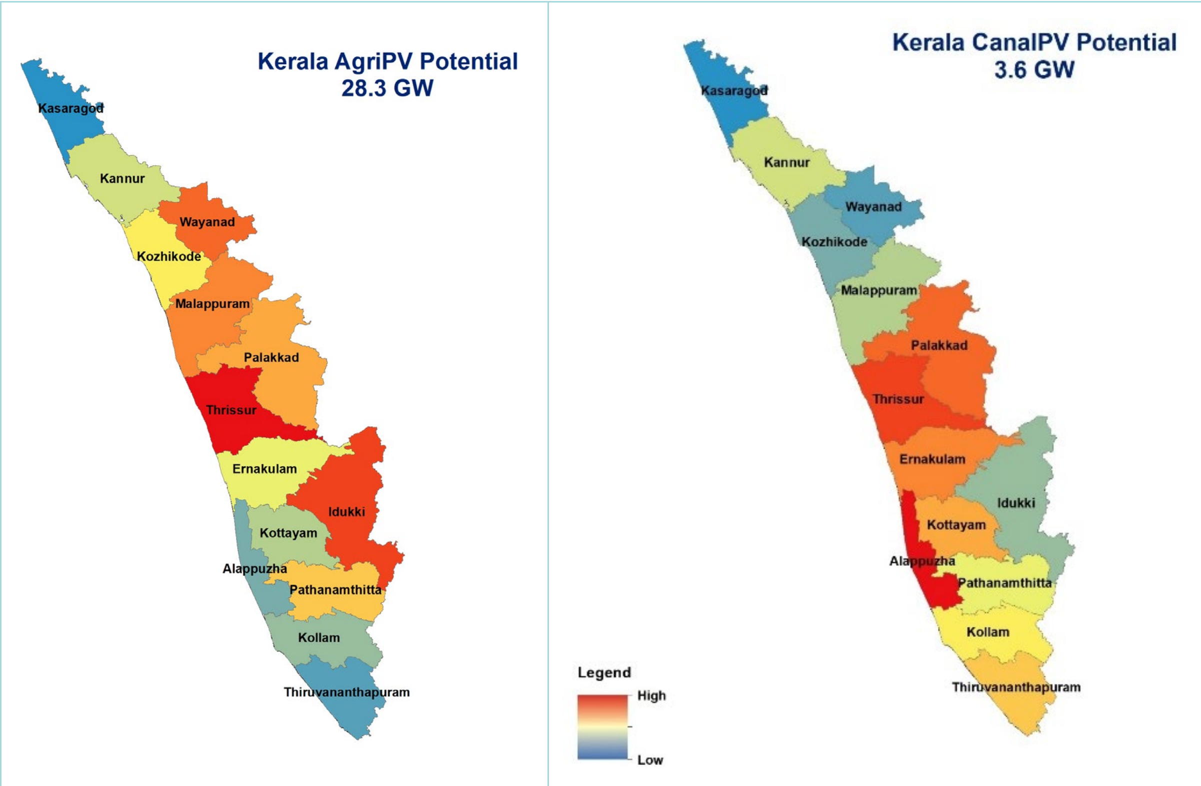


Figure 7: Solar potential assessment

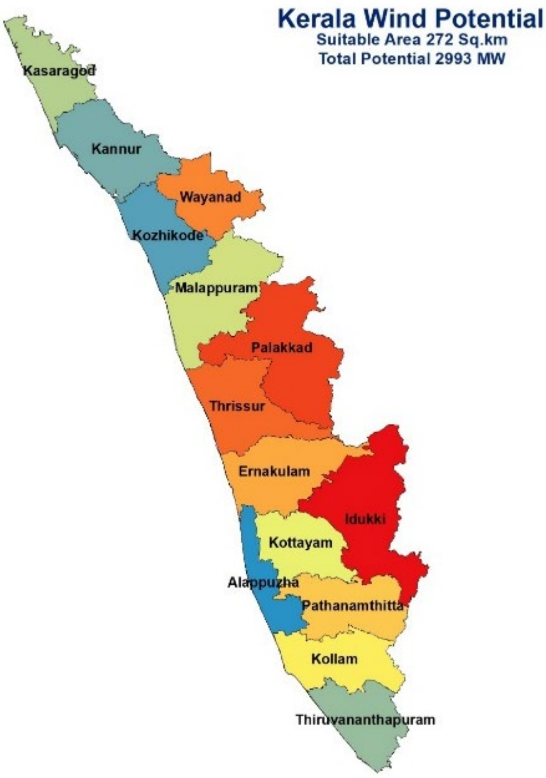


Figure 8: Wind potential assessment

The total realisable solar and wind potential in the state is around 14 GW.

For the analysis, we considered the state's hydro potential to be 3,378 MW, as estimated by CEA (MoP, 2023b). Currently, 1,856.5 MW of hydro capacity has been developed in the state and 100 MW is under development, leaving a significant potential of 1,421.5 MW (42%) untapped. The state also has a substantial pumped storage potential of 4,400 MW (Kumar, 2018), which can be explored in the near future.

Harnessing the untapped potential of hydro energy and pumped storage can play a crucial role in meeting the growing state energy demand sustainably, while reducing dependence on conventional fossil-fuel-based sources.

4.2 Supply Scenarios

For meeting the projected demand, we have analysed two supply scenarios—BAU and High-RE—for the state, as described in Figure 9.

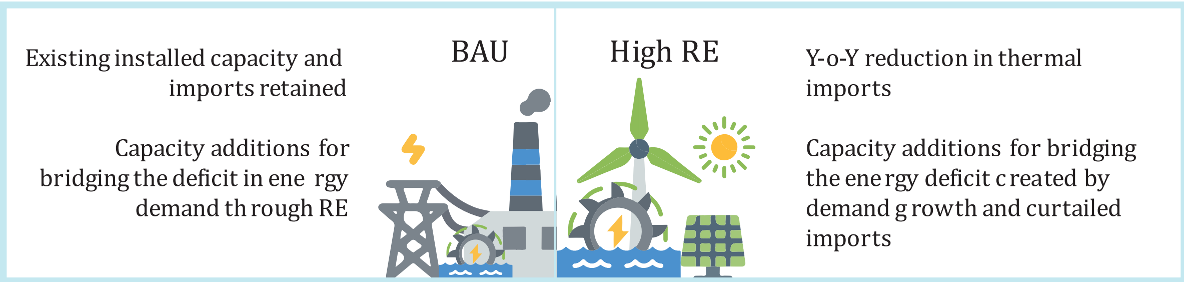


Figure 9: Supply scenarios

Assumptions and Data Considered

The following assumptions and data have been considered for the supply scenarios:

- Source-wise installed capacity and energy generation considered as per the 2021-22 Power System Statistics Report by KSEB.
- Plant load factor (PLF) of 70% considered for thermal plants on the basis of CEA's actual data performance reports (CEA, 2023a).
- PLF of 60% for hydro plants considered on the basis of data from the 2021-22 Power System Statistics Report by KSEB.
- Normative auxiliary consumption considered for thermal and hydro plants at 9% and 1% respectively.
- Capacity utilisation factor (CUF) of 18% and 23% considered for solar and wind plants, respectively.
- All the existing power purchases assumed to remain unchanged in the BAU scenario.
- RE sources planned in proportion to their potential in the state.
- Hourly generation profiles for wind derived from the RE Ninja platform.
- Solar generation profiles obtained using the CSTEM PV[11] tool.

[11] The web-based tool, CSTEP's Solar Techno-Economic Model for Photovoltaics (CSTEM-PV), functions as a valuable resource for conducting prefeasibility analyses for utility-scale solar plants, focussing on the techno-economic aspects. By accounting for factors such as seasonality, ambient temperature, and sunlight intensity at

4.2.1. Supply Scenario 1: BAU

In this scenario, we derived the demand-supply gap by comparing the projected demand with the energy supplied in the base year (FY 22), as shown in Table 14.

Table 14: Energy-demand–supply comparison

Year	Energy Requirement (MU)	Energy Supplied in FY 22 (MU)	Surplus (+)/Deficit (-) (MU)
FY 23	26,821	26,219[12]	-602
FY 25	28,451		-2,232
FY 30	32,986		-6,767
FY 35	38,505		-12,286
FY 40	45,519		-19,300

The peak-demand-supply gap was also calculated, as shown in Table 15.

Table 15: Peak-demand–supply comparison

Year	Peak Power Demand (MW)	Available Peak-Hour Supply in FY 22 (MW)	Surplus (+)/Deficit (-) (MW)
FY 23	4,474	4,374	-100
FY 25	4,746		-372
FY 30	5,503		-1,129
FY 35	6,423		-2,049
FY 40	7,594		-3,220

We foresee that the state would experience a deficit in both energy and peak demand, starting from the base year, and this will increase over the years. Hence, we formulated a capacity addition[13] plan (Y-o-Y), mainly consisting of solar, wind, and hydro sources, to meet the forecasted demand.

We estimate that a solar capacity addition of 2,942 MW by FY 30 and 8,391 MW by FY 40, and a wind capacity addition of 629 MW by FY 30 and 1,794 MW by FY 40 will be needed. Likewise, we propose capacity additions of 180 MW and 42 MW, respectively, through large- and small-hydro plants, by FY 30; and of 515 MW and 119 MW, respectively, through large- and small-hydro plants, by FY 40. Table 16 depicts the source-wise cumulative installed capacity over the timeframe

specific locations, the tool comprehensively captures the variations in solar generation. These elements play a direct role in influencing the solar radiation received by panels, consequently affecting the overall electricity generation potential.

[12] Net energy available for sale within the state, excluding open-access energy in FY 22.

[13] Capacity addition is proportionally planned as per the RE potential in the state (with solar: 69%, wind: 19%, and hydro: 13%).

considered. Detailed calculations on the scenario-wise capacity additions planned are provided in Table 3 of the Appendix.

Table 16: Source-wise existing and planned installed capacity (in MW)

Installed Capacity	FY 22 (Existing)	FY 30	FY 40
Solar	363	3,305	8,754
Wind	62.5	692	1,857
Small Hydro & Other RE	245	287	364
Sub-Total RE	***670.5***	***4,283***	***10,975***
Large Hydro	1,857	2,038	2372
Thermal (coal, gas, diesel)	3,066	3,066	3,066
Nuclear	362	362	362
Total	***5,955***	***9,749***	***16,775***

With the above capacity addition, **the RE share in the state's energy mix would increase from 4% in FY 22 to 36% by FY 40.** Figure 10 shows the share of various sources in the energy mix.

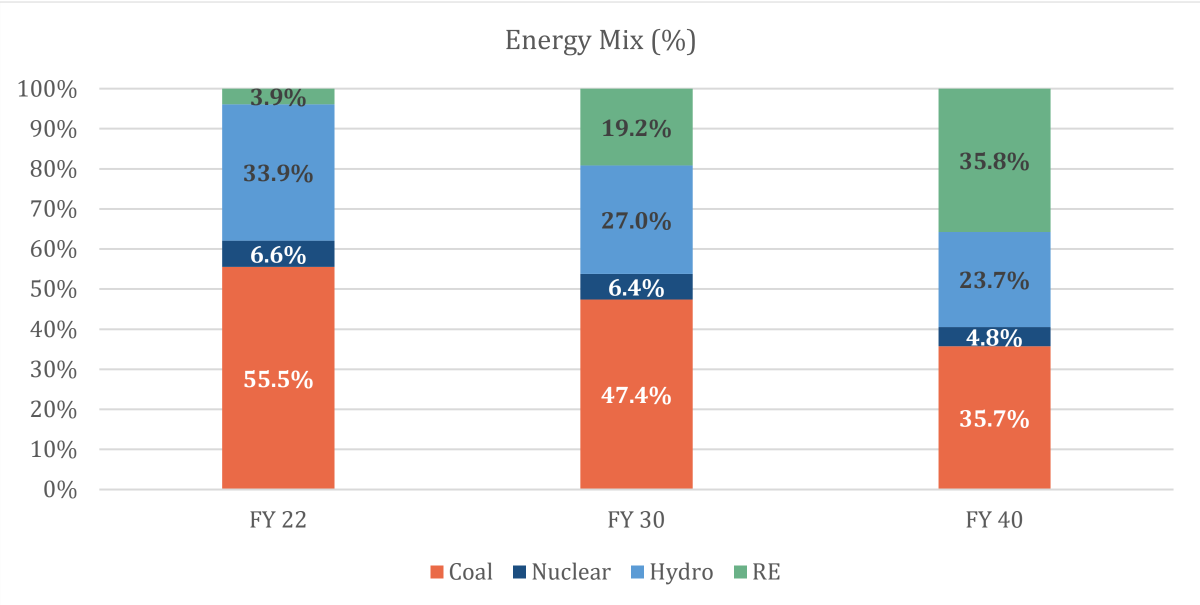


Figure 10: Source-wise energy mix for Kerala (FY 22 to FY 40)

4.2.2. Supply Scenario 2: High RE

This scenario was developed in line with the state's ambitions plans to be self-reliant and become a 100% RE-based state by 2040. Therefore, for analysing this scenario, we reduced the thermal imports and estimated the RE capacity additions required to cater to the state demand.

We considered a reduction in thermal imports from 3,066 MW in FY 25 to 180 MW by FY 40 (around 6% reduction in import Y-o-Y, starting from FY 25).

We derived the demand-supply gap by comparing the projected demand with the energy supplied in the base year (FY 22). We also considered the additional deficit created due to import reduction Y-o-Y to arrive at the total deficit, as shown in Table 17. Detailed calculations on the planned scenario-wise capacity additions are provided in Table 5 of the Appendix.

Table 17: Energy-demand–supply comparison with thermal import reduction

Year	Energy Requirement (MU)	Energy Supplied in FY 22 (MU)	Surplus (+)/Deficit (-) (MU)	Additional Deficit (-)[14] (MU)	Total Deficit (-) (MU)
FY 23	26,821	26,219	-602	0	-602
FY 25	28,451		-2,232	-1,106	-3,338
FY 30	32,986		-6,767	-6,636	-13,402
FY 35	38,505		-12,286	-12,165	-24,451
FY 40	45,519		-19,300	-17,695	-36,995

Similarly, the peak-demand-supply gap was arrived at as shown by Table 18.

Table 18: Peak-demand–supply comparison

Year	Peak Power Demand (MW)	Available Peak-Hour Supply in FY 22 (MW)	Reduction of Import (MW)	Revised Peak Supply (MW)	Total Surplus (+)/Deficit (-) (MW)
FY 23	4,474	4,374	0	4,374	-100
FY 25	4,746		180	4,194	-552
FY 30	5,503		1,082	3,292	-2,211
FY 35	6,423		1,984	2,390	-4,033
FY 40	7,594		2,886	1,488	-6,106

The deficit in both energy and peak demand will increase due to reduction in thermal imports over the years. Therefore, the capacity addition planned in this scenario needs to factor in the BAU energy deficit, as well as the deficit created due to reduction of thermal imports.

[14] Created due to reduction of thermal imports.

Since the reduction in thermal imports is considerable, we have moderated the proportion of RE sources[15] in such a way that it does not exceed the available state RE potential. Further, we have considered nuclear capacity additions, recognising its role in base operation. The capacity addition planned, along with the existing installed capacity, is given in Table 19.

Table 19: Source-wise existing and planned installed capacity (in MW)

Installed Capacity	FY 22 (Existing)	FY 30	FY 40
Solar	363	4,188	10,921
Wind	62.5	1,060	2,817
Small Hydro & Other RE	245	375	603
Sub-Total RE	***670.5***	***5,623***	***14,341***
Large Hydro	1,857	2,420	3,412
Thermal (coal, gas, diesel)	3,066	1,984	180
Nuclear	362	744	1418
Total	***5,955***	***10,771***	***19,351***

Thus, the solar capacity addition—with 3,825 MW by FY 30 and 10,558 MW by FY 40—contributes significantly to the total capacity addition, followed by wind capacity of 998 MW by FY 30 and 2,754 MW by FY 40.

Also, given the need for grid flexibility, the large- and small-hydro capacity would have to be developed. We propose capacity addition through large- and small-hydro plants (563 MW and 130 MW respectively, by FY 30; and 1,555 MW and 358 MW, respectively, by FY 40).

As thermal imports reduce, the role of nuclear sources becomes prominent in maintaining the base-load round the clock with a lower carbon footprint. Therefore, we plan an increase of 382 MW by FY 30 and 1,056 MW by FY 40 in the nuclear share for the state (Table 20).

Table 20: Share of nuclear capacity for Kerala (in MW)

FY	FY 23	FY 25	FY 30	FY 35	FY 40
Nuclear share (MW)	17	95	382	698	1,056

The energy mix with the above capacity addition is shown in Figure 11.

[15] Capacity addition is proportionally planned as per the RE potential in the state, with 45% solar; 15% wind; and 20% each of hydro and nuclear.

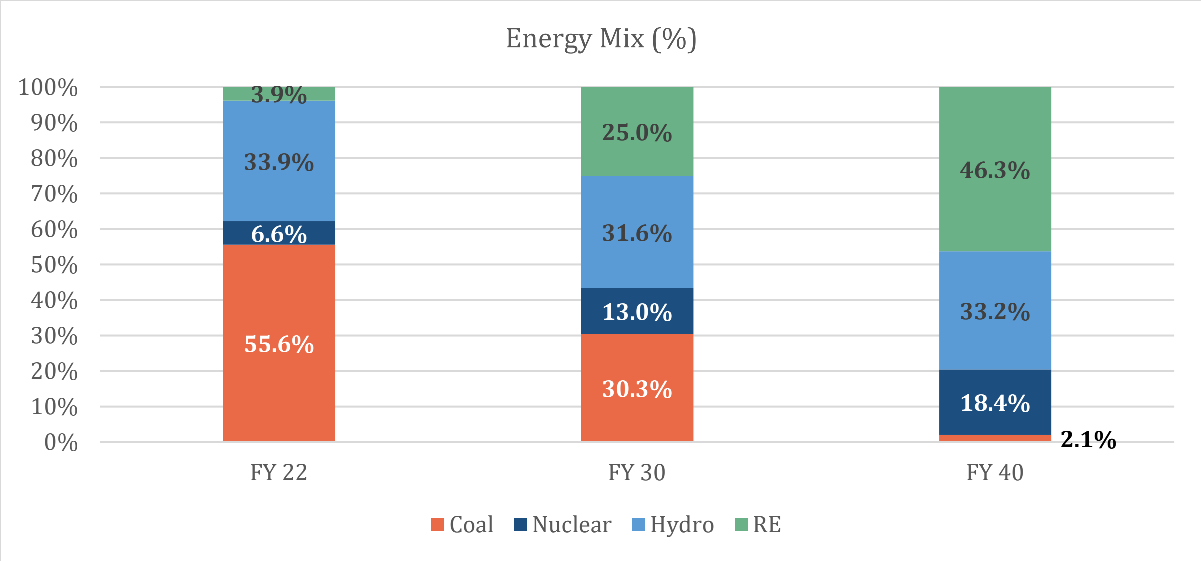


Figure 11: Source-wise energy mix for Kerala (FY 22 to FY 40)

According to our analysis, the RE share in the energy mix would increase from 4% in FY 22 to 46% by FY 40. While the thermal share will reduce from 56% in FY 22 to 2% by FY 40, the share of nuclear sources will increase from 6% in FY 22 to 19% by FY 40, indicating a clear transition towards RE.

4.2.3. Peak-Demand and Supply Analysis

We analysed the 15-minute block-wise data observed in the state for FY 16 and derived an extrapolated load curve for FY 22 (as shown in Figure 12). We extrapolated the load curves up to FY 40, assuming their shape to remain similar with growth.

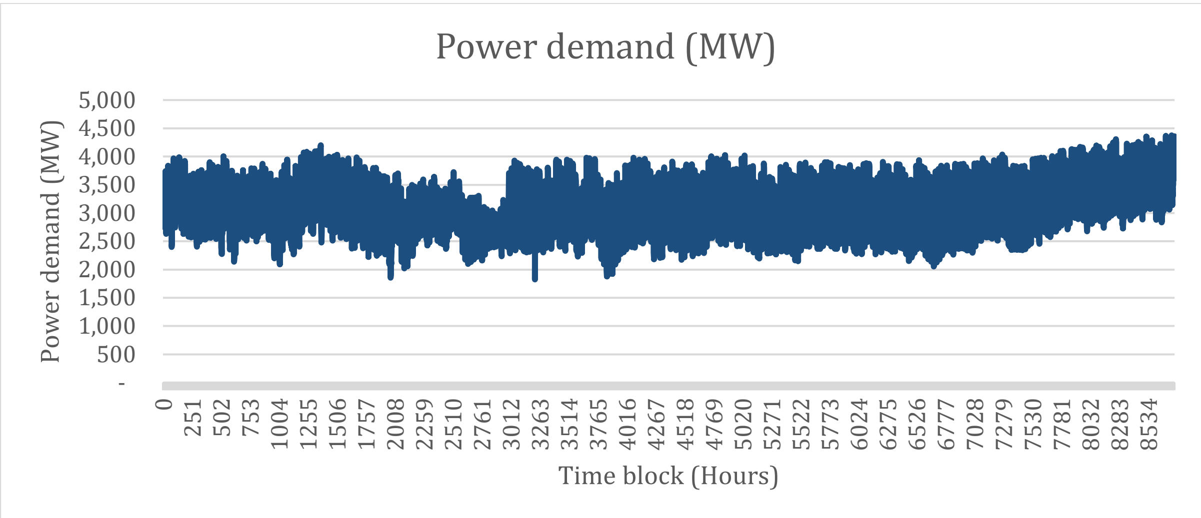


Figure 12: 15-min block-wise load curve for Kerala in FY 22

Notably, the state experiences peak demand during late-night hours and off-peak demand during early morning hours. Our analysis **identified 10:00 p.m. on 31 March as peak-day instant and 5:00 a.m. on 13 August as off-peak-day instant.**

In both scenarios, we analysed the demand-supply gap for a total of 8760 hours for FY 30 and FY 40, and estimated the optimal storage systems required to meet the gap.

Figure 13: Peak-day demand-supply gap for FY 30 and FY 40

In the BAU scenario, excess energy generation is observed during 9 a.m. to 6 p.m., mainly due to the addition of high solar capacity to the grid. However, energy deficit is observed over a longer period (from 7 p.m. to 8 a.m.) due to lack of solar power generation. On the peak day, the maximum deficit observed is 1,874 MW and 3,662 MW, respectively, at around 10 p.m. in both FY 30 and FY 40.

Similarly, under the high-RE scenario, we analysed the impact on the peak day due to reduced thermal imports and higher RE share. We see a huge gap between demand and supply over a longer period (from 7 p.m. to 8 a.m.). However, we see an energy surplus between 9 a.m. and 6 p.m., mainly due to solar power generation. The maximum deficit seen in this scenario is around 2,077 MW and 4,079 MW for FY 30 and FY 40, respectively.

We also conducted a storage analysis spanning 8,760 hours, which allowed us to identify instances of under-generation and over-generation. Through this, we estimated the optimal storage capacity required for each year. Notably, we observed that in both scenarios, the quantum of over-generation exceeded that of under-generation, indicating that the quantum of energy available for charging the storage systems is more than sufficient.

We estimated the required storage capacity, as shown in Figure 14.

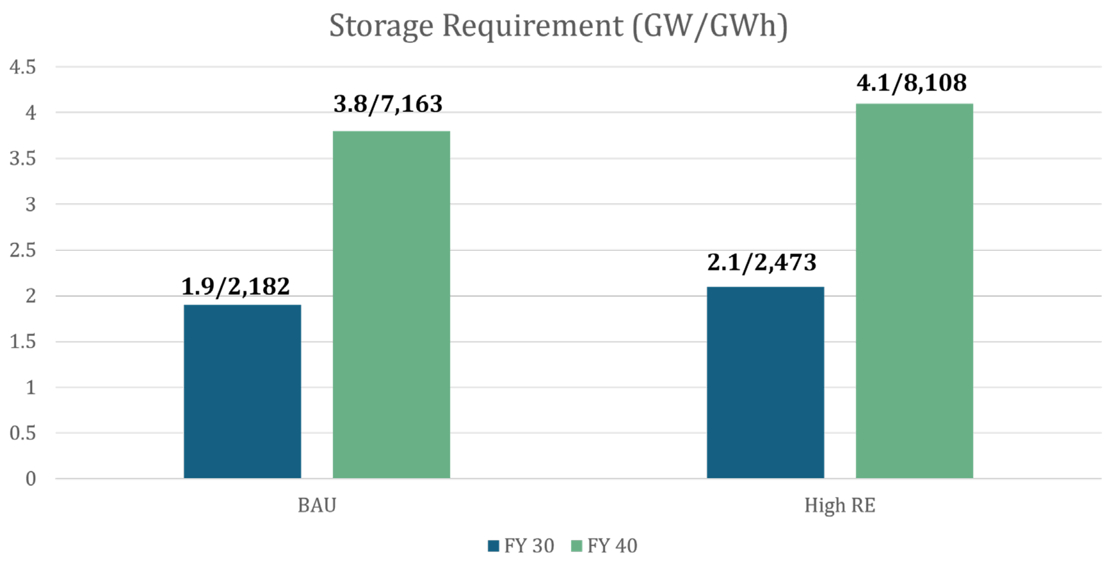


Figure 14: Scenario-wise storage requirement

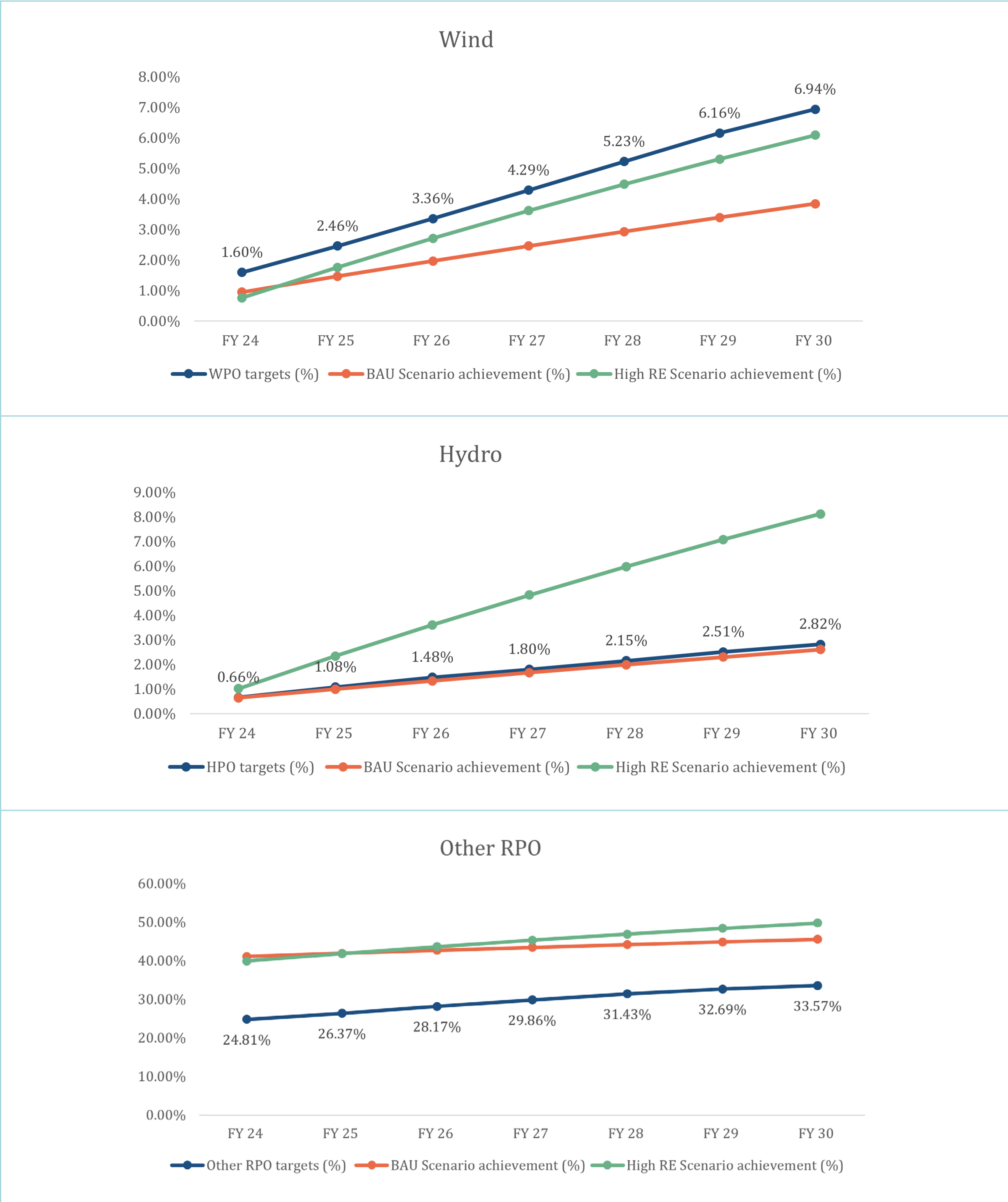
The following key inferences are drawn from the analysis:

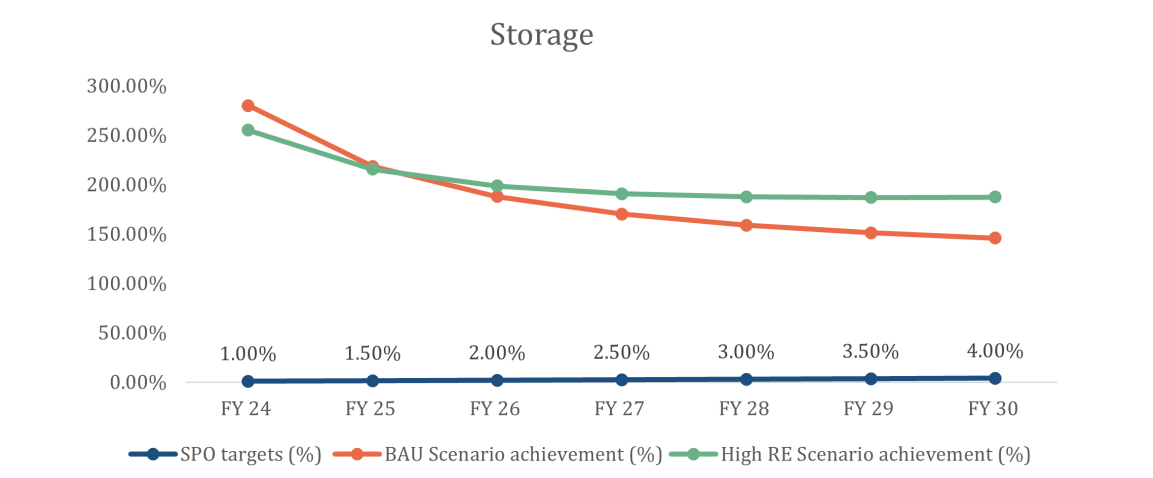
- Unlike other states, Kerala experiences peak demand during evening and night hours, which is a distinctive energy demand pattern.
- Despite extensive development of solar and wind sources, the state would be impacted by the unavailability of solar power generation in peak hours (viz., evening and night hours).
- The responsibility of meeting the peak demand falls fully on the conventional sources, which the state aims to move away from.
- While hydro sources are crucial for grid flexibility, their availability faces severe constraints during periods of lean or no rainfall in the state.
- Along with its plan for achieving 100% RE, the state should also focus on increasing the share of nuclear sources, as they can handle the base load smoothly.

RPO Compliance

We compared the energy generation from the planned RE capacity additions in both scenarios with the targets set for each energy source under the RPO targets up to FY 30, as outlined in the MoP notification dated 22 July 2022 (MoP, 2022b).

It is noted that the state will comfortably exceed the total RPO targets set but would fall short of achieving the wind targets in both scenarios. By FY 30, the hydro targets will be met in the high-RE scenario, while in the BAU scenario, there would be a slight deficit. On the other hand, the storage plans of the state would surpass the set targets, as shown in Figure 15.





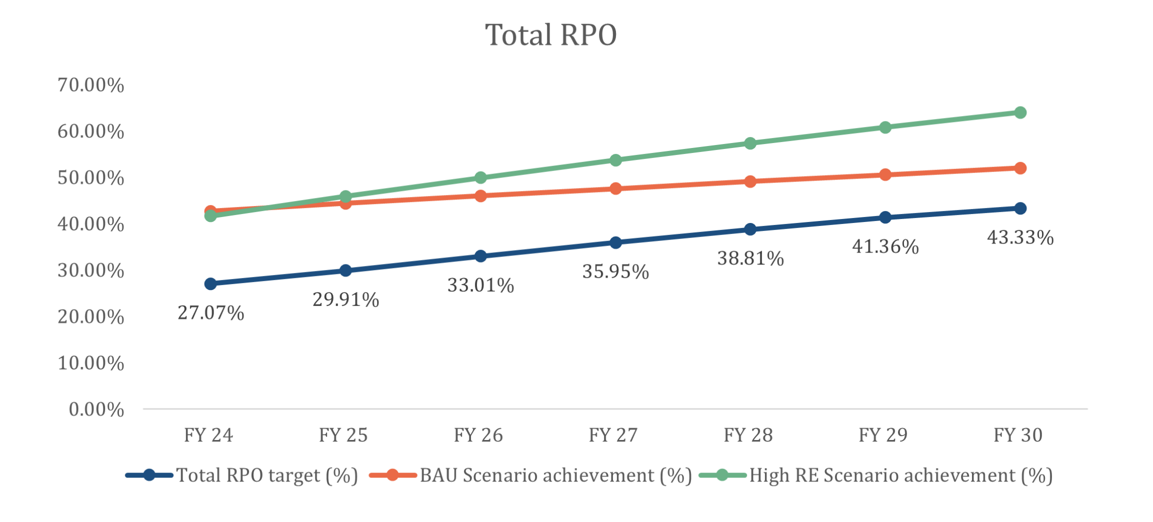


Figure 15: Source-wise RPO compliance

Though Kerala aspires to become a 100% RE-based state, meeting its night-time peak demand through RE sources is challenging, owing to the intermittent nature of RE (mainly solar in this case, which is nil during night hours). Thus, to progress on the RE front, the state needs to address this issue and plan for deploying RE—coupled with the development of storage systems—in a phased manner.

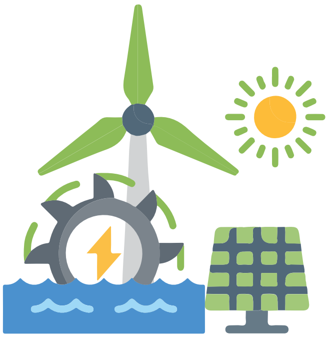
5. Conclusion and Recommendations

Our analysis shows that Kerala's energy requirement—factoring in the impact of EVs and induction cooktops penetration—will grow at a CAGR of 3% to reach 45,519 MU by FY 40. To cater to this demand, the state would need to add 8,391 MW of solar and 1,794 MW of wind capacity, while also adding large- and small-hydro plants of 515 MW and 119 MW, respectively, by FY 40 in the BAU scenario. Under the high-RE scenario, a phased reduction of thermal import is planned Y-o-Y, resulting in 10,558 MW of solar and 2,754 MW of wind capacity addition by FY 40. Given the need for grid flexibility, a nuclear capacity of 1,056 MW will need to be added by FY 40, along with large- and small-hydro capacity of 1,555 MW and 358 MW, respectively. This addition in generation capacity will have to be complemented with a storage capacity addition of 3.8 GW (7,163 GWh) in BAU scenario and 4.1 GW (8,108 GWh) in high-RE scenario. Thus, the RE share will increase from 4% in FY 22, to 36% and 46% respectively, in the BAU and high-RE scenarios by FY 40.

Based on these findings, our study puts forth recommendations for addressing the challenges faced by the state's power sector due to the rising demand itself, as well as those faced in expanding the RE generation capacity to meet this demand. The key focus areas for action by the generation and distribution sectors are identified and sector-specific measures are listed, constituting a roadmap that can help Kerala in effectively mitigating the above challenges. Additionally, relevant domestic and global practices are provided as illustrative examples.

5.1 Generation Sector

Over the years, Kerala's generation sector has depended heavily on thermal sources through imports from CGS and private entities. While the state has made significant progress in expanding its hydro capacity, it has lagged in the development of RE sources (within the state). Although the state currently meets its energy demand, it faces challenges in meeting the future demand and in attaining self-reliance with a 100% RE-based energy sector.



5.1.1 Focus Area 1: Increasing RE deployment

Based on the RE potential assessment carried out by CSTEP, it is estimated that the total realisable solar and wind potential in the state is around 14 GW. Our analysis indicated that the requirement of solar and wind capacity in the state would be in the range of 10,186 MW to 13,312 MW under both supply scenarios. To commission the capacity of such magnitude, we recommend the state to focus on increased RE deployment. The specific action points proposed are:

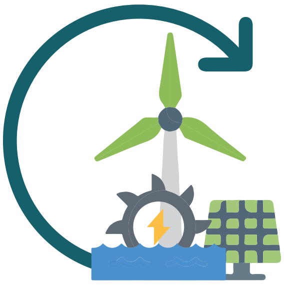
- ***Evaluate the technical feasibility of deploying various RE technologies based on resource availability, infrastructure, and land-use considerations.***
- ***Given that the state has considerable green cover, it is advisable to push for a more decentralised uptake of RE sources like solar and wind.***
- ***Devise a district-wise priority matrix of land parcels, considering various criteria like right of way (RoW), environmental clearance, ease of grid integration, etc. This can help in increasing the deployment of RE.***
- ***As interest in hybrid technologies consisting of solar PV panels and vertical axis wind turbines (VAWT) is growing, they can be piloted in the state to capture the potential of solar and wind sources.***
- ***Devise a financial model with the feed-in tariff mechanism, which guarantees grid connection to generators and a*** **minimum price** ***over a period of contract to make RE projects attractive.***
- ***Establish dedicated RE banks/funds that offer low-interest loans or grants for RE projects.***
- ***Devise alternative strategies via PPAs with other states that have abundant RE resources. This approach can help Kerala to advance its aim of becoming an RE-driven state.***

Illustrative Examples

The Chhatrapati Shivaji Maharaj International Airport (CSMIA) has partnered with WindStream Energy Technologies India to launch an innovative pilot programme, which involves the use of a unique VAWT and solar-PV hybrid system. The primary objective is to assess the feasibility of harnessing wind energy for continuous (24/7) energy generation at the airport. The applicability of this pioneering approach can be assessed for Kerala (Bose, 2023).

Germany's Renewable Energy Sources Act is also a successful example of feed-in tariff approach (*Feed-in Tariff*, n.d.). The policy aimed to incentivise RE investments by providing a minimum price for energy generation (from RE projects) and guaranteed grid connection. This made the market competitive, creating millions of new generators and increasing the number of market participants in the power sector. The feed-in tariff was around 50.6 euro cents in the year 2000 and decreased over the years to 12.7 euro cents by 2016 as the investments in RE increased (Clean Coalition, n.d.). Thus, the policy played a vital role in increasing the share of RE — from a mere 6.3% of total energy generation in 2000 to a substantial 25% in 2013, reaching a remarkable 46.2% by 2022. This model has been cited as a transferable model and has been referred to by many countries (Rechsteiner, 2020).

New York's Green Bank (*NY Green Bank*, n.d.), which aims to enable greater private investment in RE, is another notable example. The state-sponsored investment fund is dedicated to overcoming the current obstacles in clean energy financing markets and increasing overall capital availability for RE projects. While similar institutions, like the Power Finance Corporation (PFC), are already lending financial support to RE projects in India, the state can encourage more such funding agencies to dedicate the state-owned funds to small- or medium-scale RE projects. This could improve the alternative funding mechanisms, improving the uptake of RE.



5.1.2 Focus Area 2: Achieving the 100% RE goal

Transitioning to a 100% RE-based energy sector is a challenging task for a state that currently relies heavily on thermal sources. The following measures can help in this complex transition:

- ***Adopt a phased approach towards reducing thermal imports in order to minimise disruptions and ensure a smooth transition.***

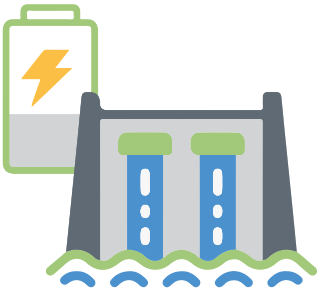
- ***Conduct a detailed assessment of both large- and small-hydro plants, and strategically plan out PPAs to overcome the intermittent nature of RE and maintain grid stability, especially during periods of high demand or low RE generation.***

- ***Initiate steps to increase the generation share from the upcoming nuclear plant in the country for achieving a resilient and low-carbon energy future.***

Illustrative Example

In alignment with its Energiwende Policy, Germany has moved from coal to RE sources (solar and wind) to expedite its clean energy transition (*Germany's Energiewende*, 2020). Clear timelines and targets have been established to gradually phase out the operational capacity of both hard-coal and lignite (soft-coal) plants by 2038. This approach includes a compensation strategy where operators of hard-coal plants receive a shutdown premium determined through a market tender process, and lignite plant operators are granted compensations amounting to 4.35 billion euros. Further, a maximum of 5 billion euros has been allocated for payments to senior workers in the mining and power sectors.

Lessons from Germany's experience can guide Kerala in planning for a phased reduction of its thermal energy imports, which is crucial for its plan to deploy a higher share of RE to meet the deficit created due to thermal import reductions.



5.1.3 Focus Area 3: Storage development

It is crucial that the state prioritises the deployment of energy storage systems as part of its RE development and phased thermal reduction plans. Based on our analysis, we recommend an optimal storage capacity development of 3.8 GW (7,163 GWh) to 4.1 GW (8,108 GWh) by FY 40 in both scenarios. The following actions are advised in this context:

- ***Explore the available PHES potential of 6.5 GW* (The Hindu, 2023)*.***

- ***Consider BESS as a viable option for providing flexibility and grid support.***

- ***Diversify storage technologies (including PHES and BESS) to harness the distinctive strengths of each technology, thus creating a reliable and sustainable energy future for the state.***

Illustrative Examples

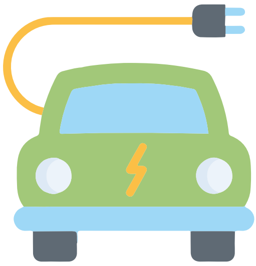
The recent MoP guidelines 'Firm and Dispatchable RE Sources Integrated With Energy Storage Systems' can be explored by the state for moving towards a dispatchable power supply—on a demand-following basis—that is reliable and flexible. This would simultaneously help the state to achieve its RPO and SPO targets (MoP, 2023).

Australia also presents a compelling example of why storage development should take precedence as RE becomes more integrated into the grid. Given Australia's substantial solar resources and the intermittent nature of energy supply in specific regions, there has been a strong push for BESS to balance the grid (CEC, 2023). As of 2022, the combined capacity of large-scale batteries under construction in the country stood at approximately 1,380 MW (equivalent to 2004 MWh). The Federal Government's substantial investment (($176 million) in battery storage, aimed at grid stabilisation and balance, is poised to exert a significant impact on the large-scale battery storage sector (Mckenzie, 2022).

Since Kerala is gearing up for its ambitious RE ventures, it would be crucial to develop comprehensive strategies for storage expansion, with particular emphasis on managing peak demand and enhancing grid flexibility.

5.2 Distribution Sector

Kerala's distribution sector is undergoing an evolution, marked by significant transformations in the conventional energy demand patterns. The adoption of emerging technologies like EVs, RTPV systems, induction cooktops, and energy-efficient solutions spanning various categories, is reshaping the sector. As such, the state needs to proactively prepare for meeting the future energy requirements to ensure energy security for its consumers.



5.2.1 Focus Area 1: Increasing EV Penetration

Our analysis estimates that the state will have 17.13 lakh EVs by FY 40 and will also witness an additional energy demand of 1,286 MU, posing considerable challenges for distribution companies (DISCOMs). It is crucial for DISCOM to closely monitor EV sales, as each EV addition increases the energy demand. Any oversight in tracking EV demand could adversely impact demand forecasting. It is also important to note that EVs are not being charged exclusively at the dedicated charging stations but are increasingly being charged at the household level. To deal with these issues, the following actions are recommended:

- ***Develop an integrated platform to map the sales of EVs tagged to the consumer installation IDs. This would help in tracking the demand of EVs in both urban and rural areas.***
- ***DISCOMs can come up with "EV charging points" campaigns, where consumers can apply for dedicated EV charging points at their households and also avail subsidies to buy chargers at a price lower than the market price through a single-window facility.***
- ***DISCOMs can leverage the funds offered by the central government's Revamped Distribution Sector Scheme (RDSS) to install smart meters at residential and commercial premises. This would further help to segregate EV demand from residential load and can also enable its effective monitoring for demand forecasting.***
- ***Introducing time-of-day (ToD) tariffs could play a crucial role in efficiently managing peak demand. These tariffs incentivise consumers to charge their EVs during non-peak hours and promote the adoption of demand-response measures.***
- ***While the state has introduced innovative solutions, such as distribution of pole-mounted charging units, there is a need to place greater emphasis on formulating comprehensive state-level plans for charging-infrastructure development.***
- ***The municipalities of major towns need to promote sustainable and cleaner transportation by offering priority parking spaces, discount on toll or parking charges, etc., to encourage EV adoption while reducing emissions.***
- ***The state needs to carry out a detailed grid-level load-flow analysis to evaluate the technical feasibility of EV integration into the distribution grid. Such studies play a vital role in pinpointing the potential grid constraints and identifying the need for network strengthening and upgradation at various levels.***

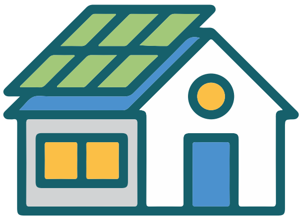
Illustrative Examples

Delhi has created a single-window facility for applying for subsidy, which has been provided for buying EV chargers at a price lower than the market price (Kumari, 2023).

Germany's local-level government-driven EV transition (EVA, 2022) provides valuable insights for Indian states and town municipalities seeking to promote sustainable and clean transportation. By offering discounts on tolls, providing free parking spaces for EVs, and creating zero-emission zones in city centres and tourist destinations, states can encourage EV adoption while reducing emissions. While discounted tolls incentivise EV usage, making it a cost-effective choice for commuters, free parking spaces in major cities not only make EVs more convenient but also lower the cost of owning them, further promoting their adoption. The creation of zero-emission zones, coupled with charges on internal combustion engine (ICE) vehicles, can significantly improve air quality and reduce traffic-related pollution, contributing to a healthier and more sustainable urban environment.

The European EV Charging Infrastructure Masterplan developed for e-mobility, encompasses charging-infrastructure expansion across diverse vehicle segments. It offers vital policy insights, emphasising the need for interoperability and standardisation in charging solutions to reduce range anxiety and enhance convenience for EV users. On similar lines, Charging Our Future—the long-term vision and strategic plan for Aotearoa New Zealand's EV charging infrastructure—can also serve as a reference for developing state-level EV master plans (Ministry of Transport,Newzeland, 2023).

A load-flow study conducted by CSTEP in a selected feeder under Bangalore Electricity Supply Company Limited identified bottlenecks that the network will face due to EV penetration. Similar studies can be piloted to identify grid constraints and enable informed network upgrades in select cities.



5.2.2 Focus Area 2: Decentralising energy generation through RTPV

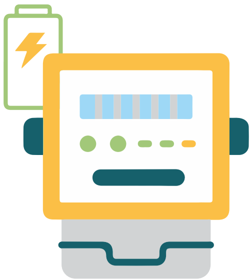
Kerala had a target of installing 800 MW of RTPV systems by FY 22. However, as of August 2023, the state's cumulative RTPV capacity stood at 512 MW. Given the role of decentralised energy sources in paving the way for self-reliance, the state should proactively consider enhancing the deployment of RTPV through the following ways:

- ***Mapping potential sites/buildings for installing RTPV systems through drone-based aerial photogrammetry.***
- ***Piloting peer-to-peer energy trading, where the RTPV prosumers (individuals who produce and consume energy) can sell the energy generated through an energy trading hub. This would enhance the uptake of RTPV and also encourage consumer engagement in decentralised energy market mechanisms.***
- ***Introducing a green building programme, where installation of rooftop solar systems is mandated in the newly constructed buildings, with the provision of certain tax concessions, free electricity connection, and other benefits for these buildings, thus promoting RTPV uptake.***
- ***Focussing on roof-leasing models, where a building owner would lease his/her roof for installing RTPV systems and, in turn, receive electricity at lower rates.***
- ***Taking up initiatives like community-centric RTPV can also enable the state to boost RTPV uptake.***
- ***Finally, multilateral financing institutions can be brought in to reduce the cost and enhance tenure financing for all consumer categories.***

Illustrative Examples

Brooklyn Microgrid—a blockchain-based platform for locally trading electricity in New York City—underscores the potential of decentralised energy generation to empower prosumers. Policymakers can harness this model to enhance grid resilience and promote the transition to RE sources. Such initiatives can also drive the transformation of energy landscape (where consumers can be prosumers), making it more sustainable, resilient, and accessible to a wide consumer base (Mok, 2016).

"Community Solar in Brazil" is a unique initiative where a group of people who desire to generate their own energy can invest in RE systems and reap the benefits without individual installations. There are multiple financial models (like own resource, external financing, PV-system leasing), which can be opted for according to the need. Such initiatives can be replicated by Kerala to boost the uptake of renewables (Schneider, 2019).



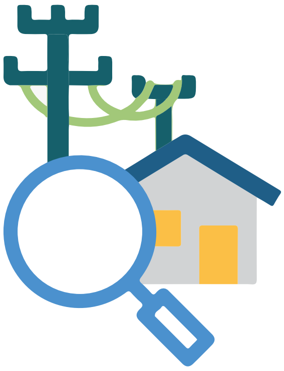
5.2.3 Focus Area 3: Promoting behind-the-meter storage

Behind-the-meter storage (BMS) is a battery storage system located behind the meter at a consumer premise, connected to the distribution network. While consumers have traditionally relied on the uninterruptible power supply (UPS) systems to ensure uninterrupted power during outages, the BMS concept is gaining traction in today's era of technological advancements (NREL, n.d.). Given that the higher share of power demand in the state comes from domestic consumers, these would be vital in shaping the distribution sector. Accordingly, the following actions are recommended:

- ***Pilot behind-the-meter storage to assess its feasibility and obtain the twin benefit of efficiently managing peak demand and attaining reliability during interruptions.***
- ***Conduct techno-economic analyses for public-private partnership for large-scale roll-out of decentralised virtual power plants (VPPs).***

Illustrative Examples

Japan's behind-the-meter (BTM) virtual power plant model highlights the effectiveness of public-private partnerships in driving residential energy storage adoption, as demonstrated by the collaboration with ENERES (Gordon, 2019). Under the model, residential consumers are provided with BMS at no upfront cost, which promotes decentralisation and energy resilience. The dual role of these BMS batteries—as emergency power sources during outages and grid assets for capacity transactions—underscores their versatility and value. This approach encourages active participation from consumers in grid services, emphasising the importance of customer engagement and advanced energy management solutions. Policymakers can draw insights from this model to launch similar partnerships and incentivise consumer involvement in enhancing grid reliability and flexibility through distributed energy sources.



5.2.4 Focus Area 4: Monitoring energy demand and energy efficiency in the residential sector

Since residential consumers make up a substantial share of Kerala's energy demand, it is crucial for the state to actively drive energy efficiency (EE) initiatives. Although the state has already promoted various EE measures, such as the distribution of LEDs and energy-efficient fans, there is still room for improvement within the residential sector. Additionally, it is vital for the state to remain vigilant regarding technological advancements in this sector, as they can potentially result in increased energy demand. An example of such advancements is the adoption of induction cooktops. Our analysis on the penetration of induction cooktops found that the increasing interest in induction cooktops could increase the energy demand by 416 MU by FY 2040. Similarly, the evolving landscape of electronic gadgets can have considerable implications for energy demand, thus requiring careful monitoring of energy consumption trends and demands. Accordingly, we recommend the following actions:

- ***Conduct pilot studies to understand the change/ shifts in consumer behaviour in the context of tech-intensive households.***
- ***Promote energy audits and home assessments for residents to identify areas where EE improvements can be made.***
- ***Introduce financial incentives, rebates, and subsidies for energy-efficient appliances and home upgrades.***
- ***Develop programmes that reward residents for adopting energy-efficient practices, such as reducing energy consumption during peak hours.***
- ***Develop applications that enable consumers to gain hassle-free access to real-time energy consumption data, for encouraging energy saving behaviours.***

Illustrative Examples

The Green Home Grants programme by the Government of the United Kingdom (*Green Homes Grant*, 2020) aims for enhanced EE measures in households. Under this programme, households receive vouchers to facilitate the adoption of energy-efficient upgrades, such as replacing appliances like televisions, refrigerators, and fans with BEE star-rated models. These initiatives not only encourage active consumer engagement in EE measures but also provide financial support to consumers. The state needs to carefully assess the larger benefits that can be reaped through such initiatives.

5.2.5 Focus Area 5: Peak-demand management

A critical challenge confronting the state relates to its demand patterns, with peak demand typically occurring during night-time hours when solar generation is nil. This necessitates that DISCOMs focus on how they can smoothly manage these peak demand periods.

The following actions are recommended to efficiently manage the peak demand:

- ***Implementing time-of-use (ToU) tariff structures that charge consumers with higher electricity rates during peak hours and lower rates during off-peak times. This would encourage consumers to shift energy-intensive activities to non-peak hours.***

- ***Implementing demand response programmes at feeder level can be effective as they prioritise the consumers on the basis of loads. Whenever the consumers agree to decrease their electricity usage in response to grid signals during peak periods, they will receive benefits in the form of financial incentives, rebates, or reduced tariffs.***

- ***Implementing automated demand response for EV charging points at the residential level can enable DISCOMs to remotely monitor and control energy usage.***

Illustrative Examples

Kerala can draw valuable policy insights from South Australia's home battery subsidies to implement similar incentives for encouraging residential consumers to adopt home battery storage systems (Government of South Australia, n.d.). By offering financial support for battery installations, Kerala can promote the adoption of solar energy, improve grid stability, and reduce the strain on the energy grid during periods of low solar generation or at night peak hours. These subsidies should emphasise cost savings for homeowners, support grid reliability by allowing the injection of stored energy during peak demand, and encourage the pairing of home batteries with rooftop solar installations. Additionally, public awareness campaigns, regulatory support, and push for domestic battery manufacturing facility are essential components for the success of such a programme.

California's adoption of time-of-use (TOU) pricing also provides a crucial policy insight by showcasing how dynamic pricing models can effectively shape consumer behaviour, optimise energy consumption, and mitigate the burden of peak demand on the grid (EDF, n.d.). TOU pricing aligns with the goals of RE integration and grid stability, by encouraging energy use during off-peak hours when the availability of RE sources is higher. Additionally, it highlights the importance of considering equitable impact on various consumer segments (offering assistance programmes to vulnerable communities), while also emphasising the role of education in facilitating a smooth transition. This policy insight highlights the potential of TOU pricing in achieving sustainable and efficient energy consumption, while supporting the integration of clean energy sources.

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7. Appendix

Table1: Consumer-category-wise projected electricity demand (in MU)

Category	Growth rates %	FY 23	FY 24	FY 25	FY 26	FY 27	FY 28	FY 29	FY 30	FY 31	FY 32	FY 33	FY 34	FY 35	FY 36	FY 37	FY 38	FY 39	FY 40
Domestic	**4%**	13,127	13,591	14,071	14,569	15,083	15,616	16,168	16,739	17,331	17,943	18,577	19,233	19,913	20,617	21,345	22,099	22,880	23,688
Commercial-LT	**3%**	3,401	3,495	3,592	3,691	3,793	3,898	4,005	4,116	4,229	4,346	4,466	4,590	4,716	4,847	4,980	5,118	5,259	5,404
Industrial-LT	**1%**	1,174	1,184	1,193	1,202	1,212	1,221	1,231	1,240	1,250	1,260	1,270	1,280	1,290	1,300	1,310	1,320	1,331	1,341
HT-EHT	**2%**	4,875	4,981	5,089	5,199	5,312	5,427	5,545	5,665	5,788	5,914	6,042	6,173	6,307	6,444	6,584	6,726	6,872	7,021
Public lighting	**0.5%**	379	380	382	384	386	388	389	391	393	395	397	398	400	402	404	406	408	410
Railway traction	**6%**	351	374	398	424	451	480	511	544	579	616	656	699	744	792	843	897	955	1,017
Licensees	**1%**	624	631	639	648	656	664	673	681	690	699	707	716	725	735	744	753	763	773
Agricultural LT	**4%**	390	407	424	442	461	480	501	522	544	567	592	617	643	670	699	728	759	792
BAU demand (MU)	**3%**	**24,321**	**25,043**	**25,788**	**26,558**	**27,353**	**28,174**	**29,023**	**29,899**	**30,804**	**31,740**	**32,707**	**33,706**	**34,738**	**35,805**	**36,908**	**38,049**	**39,227**	**40,446**
EV demand (MU)		34	57	79	102	126	149	173	198	249	302	355	408	462	624	788	953	1119	1286
Induction cooktop demand (MU)		12	24	37	49	62	75	89	102	130	159	188	218	249	281	313	346	380	415
Final demand (MU)		**24,367**	**25,124**	**25,904**	**26,710**	**27,541**	**28,399**	**29,285**	**30,199**	**31,184**	**32,200**	**33,250**	**34,332**	**35,450**	**36,710**	**38,009**	**39,347**	**40,727**	**42,147**
T&D Loss trajectory (%)		10.07%	9.95%	9.83%	9.71%	9.59%	9.47%	9.35%	9.23%	9.11%	8.99%	8.86%	8.74%	8.62%	8.50%	8.37%	8.25%	8.12%	8.00%
Final demand with T&D loss (MU)		**26,821**	**27,624**	**28,451**	**29,304**	**30,183**	**31,089**	**32,023**	**32,986**	**34,024**	**35,094**	**36,197**	**37,333**	**38,505**	**39,829**	**41,191**	**42,593**	**44,035**	**45,519**

Table 2: Kerala's monthly power requirement and availability

Month	Requirement (MU)	Availability (MU)	Peak Demand (MW)	Peak Availability/Peak Demand Met (MW)
Apr-21	2,420	2,419	4,261	4,235
May-21	2,055	2,051	3,882	3,880
Jun-21	2,014	2,014	3,593	3,593
Jul-21	2,073	2,073	3,618	3,618
Aug-21	2,108	2,107	3,895	3,591
Sep-21	2,158	2,158	3,761	3,761
Oct-21	2,201	2,200	3,747	3,742
Nov-21	2,112	2,112	3,680	3,680
Dec-21	2,279	2,279	3,830	3,825
Jan-22	2,316	2,316	3,892	3,889
Feb-22	2,217	2,216	4,038	4,038
Mar-22	2,659	2,659	4,374	4,374

Table 3: BAU scenario: Capacity addition calculations for sample years

<table>
<tr><th rowspan="3">Supply scenario</th><th>Financial year</th><th>Particulars</th><th>2022-23</th><th>2023-24</th><th>2024-25</th></tr>
<tr><td>Total demand (MU)</td><td>A</td><td>26,821</td><td>27,624</td><td>28,451</td></tr>
<tr><td>Net energy available for sale inside state in FY 22</td><td>B</td><td colspan="3">26,219</td></tr>
<tr><td rowspan="11">BAU</td><td>Deficit (MU)</td><td>C=A-B</td><td>602</td><td>1,405</td><td>2,232</td></tr>
<tr><td>Capacity Addition (MU)</td><td colspan="4">Capacity addition is proportionally planned as per RE potential in state with solar: 69%, wind: 19%, and hydro:13%</td></tr>
<tr><td>Solar</td><td>D=C*69%</td><td>413</td><td>963</td><td>1,530</td></tr>
<tr><td>Wind</td><td>E=C*19%</td><td>113</td><td>263</td><td>418</td></tr>
<tr><td>Hydro</td><td>F=C*13%</td><td>77</td><td>179</td><td>284</td></tr>
<tr><td>Cumulative Capacity Addition (MW)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Solar</td><td>S=(D*1000)/(18%CUF*8760)</td><td>262</td><td>611</td><td>970</td></tr>
<tr><td>Wind</td><td>W=(E*1000)/(23%CUF*8760)</td><td>56</td><td>131</td><td>208</td></tr>
<tr><td>Hydro</td><td>H=(F*1000)/(44%PLF*8760)</td><td>20</td><td>46</td><td>73</td></tr>
<tr><td>Total</td><td>=S+W+H</td><td>338</td><td>788</td><td>1,251</td></tr>
</table>

Table 4: Y-o-Y cumulative capacity addition from FY 23 to FY 40

BAU scenario	FY 23	FY 24	FY 25	FY 26	FY 27	FY 28	FY 29	FY 30	FY 31	FY 32	FY 33	FY 34	FY 35	FY 36	FY 37	FY 38	FY 39	FY 40
Solar	262	611	970	1,341	1,723	2,117	2,523	**2,942**	3,393	3,859	4,338	4,832	5,342	5,917	6,510	7,119	7,746	8,391
Wind	56	131	208	287	369	453	540	**629**	726	825	928	1,033	1,142	1,265	1,392	1,522	1,657	1,794
Hydro	20	46	73	101	130	160	191	**222**	256	292	328	365	404	447	492	538	585	634
Total	**338**	**788**	**1,251**	**1,729**	**2,222**	**2,730**	**3,254**	**3,794**	**4,375**	**4,975**	**5,594**	**6,231**	**6,888**	**7,630**	**8,394**	**9,179**	**9,988**	**10,820**

Table 5: High RE scenario: Capacity addition calculations for sample years

Supply scenario	Financial year	Particulars	2022-23	2023-24	2024-25
	Total demand (MU)	A	26,821	27,624	28,451
	Net energy available for sale inside state in FY 22	B	26,219		
High RE	**Deficit (MU)**	C=A-B-T	602	1,405	3,338
	Target Y-o-Y reduction 6% in Import (MU)	T	0	0	1105.924235
	Capacity Addition (MU)				
	Solar	D=C*45%	271	632	1,502
	Wind	E=C*15%	90	211	501
	Hydro	F=C*20%	120	281	668
	Nuclear	G= C*20%	120	281	668
	Cumulative Capacity Addition (MW)	Capacity addition is proportionally planned as per RE potential in the state, with 45% solar; 15% wind; and 20% each of hydro and nuclear.			
	Solar	S=(D*1000)/(18%CUF*8760)	172	401	953
	Wind	W=(E*1000)/(23%CUF*8760)	45	105	249
	Hydro	H=(F*1000)/(44%PLF*8760)	31	73	173
	Nuclear	N=(F*1000)/(80%PLF*8760)	17	40	95
	Total	**=S+W+H+N**	**265**	**618**	**1,469**

Table 6: Y-o-Y cumulative capacity addition from FY 23 to FY 40

High-RE scenario	FY 23	FY 24	FY 25	FY 26	FY 27	FY 28	FY 29	FY 30	FY 31	FY 32	FY 33	FY 34	FY 35	FY 36	FY 37	FY 38	FY 39	FY 40
Solar	172	401	953	1,512	2,078	2,652	3,234	3,825	4,437	5,058	5,688	6,328	6,978	7,671	8,376	9,091	9,819	10,558
Wind	45	105	249	394	542	692	844	998	1,157	1,319	1,484	1,651	1,820	2,001	2,185	2,372	2,561	2,754
Hydro	31	73	173	274	377	481	586	693	804	916	1,031	1,147	1,264	1,390	1,518	1,647	1,779	1,913
Nuclear	17	40	95	151	208	265	323	382	444	506	569	633	698	767	838	909	982	1,056
Total	**265**	**618**	**1,469**	**2,331**	**3,204**	**4,090**	**4,988**	**5,898**	**6,842**	**7,799**	**8,771**	**9,758**	**10,761**	**11,830**	**12,916**	**14,020**	**15,141**	**16,281**

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