Analyzing Viability of Energy Storage Systems (ESS) at the Sub-national level

Draft for Discussion

March 2025

Scope of work

1

Steps and activities

Data Collection and Analysis

Section 1- Comprehensive analysis of Kerala power sector

- Study of electricity mix, RE potential, and load curves and analysis of seasonal and monthly variation in demand in Kerala

Section 2- Future demand projections and storage potential by FY27

- Analyze the expected change in demand pattern over the years based on the available data
- Undertake consultations with the concerned stakeholders to validate the demand patterns
- Undertake high-level estimation of the optimal capacity, costs as well as duration of ESS required to cater to possible demand shortages

Section 3- Developments in the Energy Storage System sector

- Examine battery storage technology efficiency metrics such as round-trip efficiency, degradation rates, and lifecycle costs
- Outlining the key market trends in deployment of ESS technologies such as BESS and PSP, including cost trends, analysis of business model, procurement mechanisms and cost discovery trends
- Undertake comparative assessment of the various ESS technologies such as BESS and PSP based on key parameters such as costs, efficiency, performance, gestation period etc.

Preliminary recommendations

Section 4- Analysis outcomes and preliminary recommendations

- Identify and come up with preliminary recommendations regarding the various initiatives that can be undertaken to deploy various ESS technologies; provide estimations of costs and investments for these technologies.

2

Next Steps

- **Organize a consultative roundtable/ workshop to gather views and inputs from various stakeholders involved in the Kerala power value chain**

Kerala's Renewable Energy Sector

The transition to renewable energy sources is crucial for mitigating climate change and achieving sustainable development. Kerala is emerging as a leader in renewable energy adoption, having already deployed over 3,229 MW of RE capacity, (including large hydro), a nearly 50% share of the total installed electricity capacity of 6,669 MW in the state as of FY24. Additionally, as per the National Electricity Plan, no conventional, hydro, or nuclear capacity addition is planned till FY32, and hence all of the planned capacity addition will be from renewable energy sources.

Kerala is also taking steps for greening the transportation sector

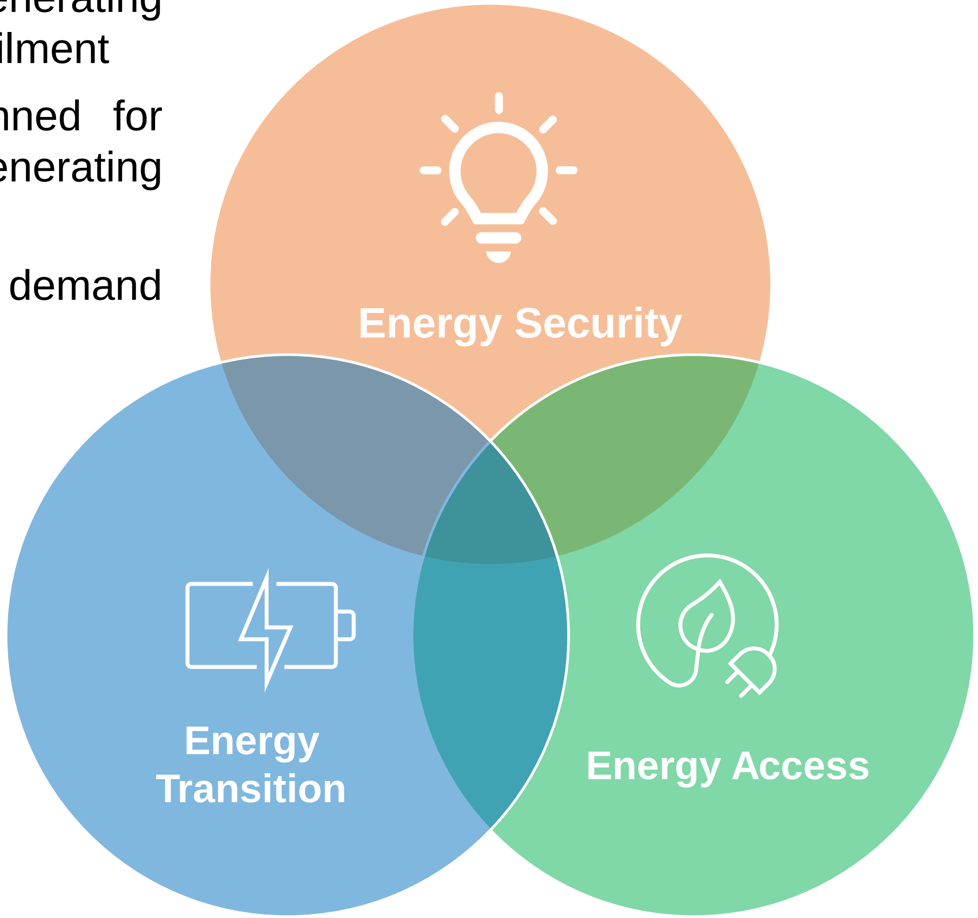
- The state has the second highest overall electric vehicle penetration rate in India, at ~11.1%,
- Kerala is the leading state in terms of electric passenger vehicle penetration, with a ~5.4% penetration

Kerala's ambitious RE targets will ensure further sectoral growth in coming years

- The state plans aims to add 3,000 MW through solar and wind energy projects and 1,500 MW from hydro power projects by 2027
- Kerala has set ambitious goals to achieve 100% renewable energy by 2040 and become carbon neutral by 2050

Kerala faces challenges on all three energy fronts namely energy security, energy transition and energy access

- Over-reliance on central thermal generating stations for energy consumption fulfilment
- No further capacity addition planned for hydro, nuclear or thermal generating stations
- 10.7% rise in energy consumption demand in FY24



- Untapped renewable energy potential in rural areas and for low-income households
- Affordability concerns- one of the highest effective electricity tariffs for domestic consumers
- Domestic consumption contributing to 50% of overall energy consumption

- Highly untapped solar potential; only 12% of total solar potential realized till date
- Excessive dependency on hydro sources
- Absence of energy storage capacity to manage grid intermittency and for providing firm renewable energy power

In recent years, Kerala has been facing challenges in meeting its power demand

Formation of duck curve due to increasing solar generation

Increasing demand for electric vehicle charging

Surge in air conditioner usage

Rapid rise in peak demand in last 1 year

Late evening/night peak demand

- The combination of meeting growing electricity demand while managing grid integration of variable renewable energy sources can prove to be a significant obstacle to Kerala as it seeks to accelerate its energy transition without compromising the stability of its electricity grid.
- With the increasing proportion of variable and intermittent resources, energy storage system technologies such as battery energy storage system and pump storage projects will play a crucial role in ensuring grid stability and in meeting peak demand requirements.

Need of the study

- A study conducted during the years 2022-23 projected the storage potential of 4.1 GW in Kerala by the end of FY40. However, two major challenges have emerged since then:
  - Increased late evening/nigh peak demand, driven by the adoption of energy-intensive appliances like air conditioners and electric vehicles.
  - Evolving energy storage system landscape, with reductions in cost and improvements in technology, which has significantly improved commercial viability.
- Optimal planning for deployment of Energy Storage Systems has become crucial for addressing the peak demand challenges faced by the state.
- As a result, there is a pressing need to conduct a new study to evaluate the future storage requirements as per the evolving power sector scenario in the state.
- This study will help in understanding the evolving energy storage landscape and guide future investments and policies to optimize energy resources efficiently.

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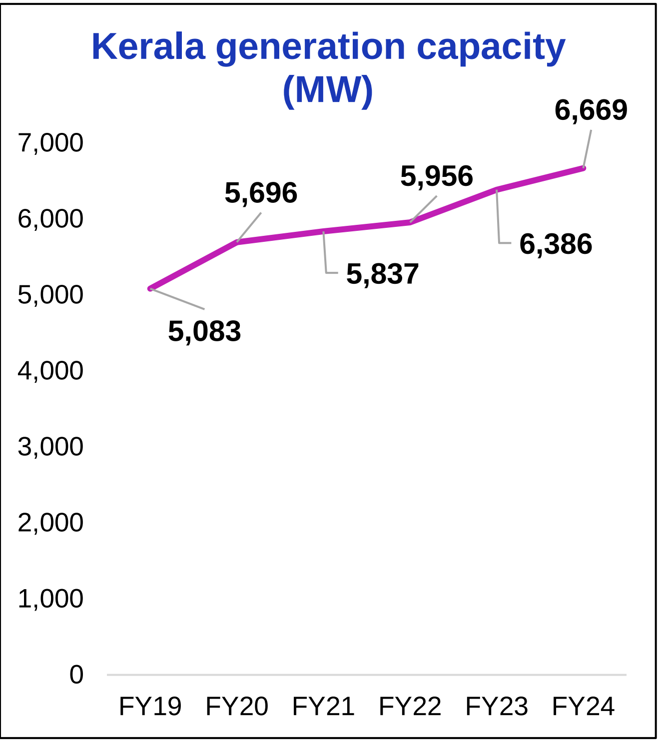
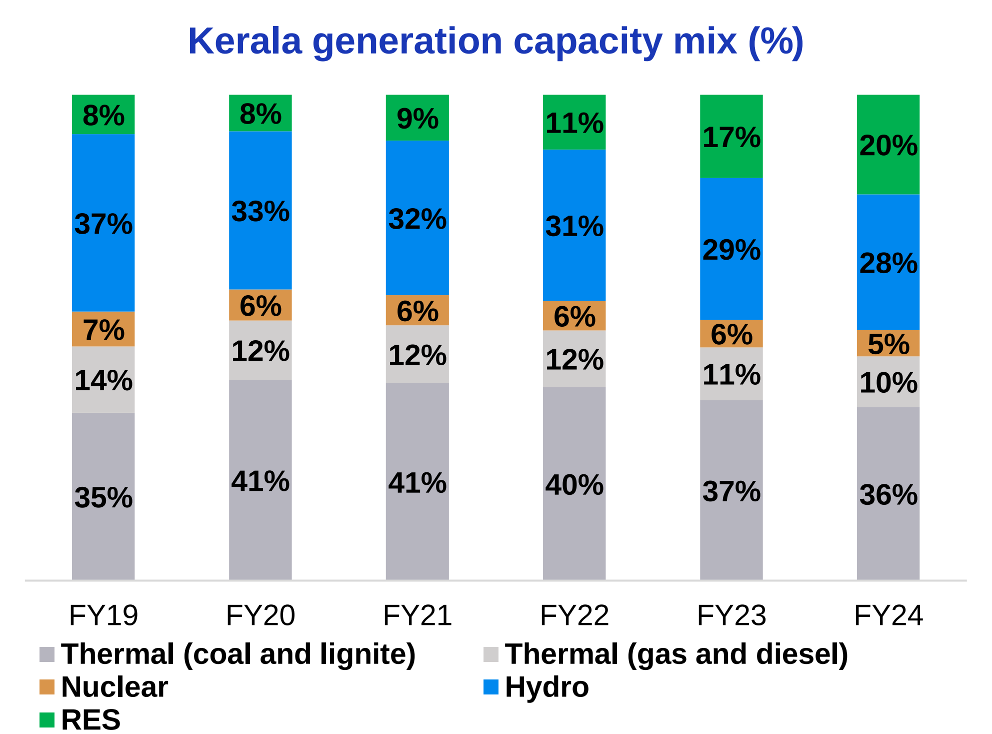
Analysis of Kerala power sector

Kerala power sector overview





Kerala generation capacity (MUs)

Source	FY 24
Thermal	17,398
Nuclear	2,162
Hydro	5,600
RES	1,125
Power exchanges	3,641
SWAP	844
Deviation Settlement Mechanism	464
Total	**~31,240**

- The total generation capacity* of Kerala stood at 6,669 MW, as of March 2024.
- As of March 2024, thermal constitutes 46% of the total capacity, followed by hydro (28%), and nuclear energy (5%). The remaining 20% (1,365 MW) is contributed by solar, wind, small hydro, and other renewable energy (RE) sources.
- RE share in the state electricity mix have grown from 8% (413 MW) to 20% (1,365 MW), with a compounded annual growth rate (CAGR) of 27% in last 5 years.

*Note: *it includes installed as well as allocated share for Kerala state*

Source: All India installed capacity (in MW) of power stations report by CEA, Annual Administration report by KSEBL

Kerala has immense RE potential across different sources which largely remains untapped

- The solar potential in the state is ~30 GW, spread across various solar categories such as rooftop solar, ground-mounted solar, agri-photovoltaic, and others. Solar rooftops are a major contributor to this potential, accounting for ~ 19 GW of solar energy potential in the state.
- The area suitable for deployment of wind plants is around 272 sq. km, with a wind potential of around 3 GW**.** Idukki, Palakkad, Thrissur, and Wayanad districts have the highest potential.
- As per the Central Electricity Authority (CEA), the assessed hydro potential in the state of Kerala is ~ 3,378 MW. As of March 2023, around 1,860 MW (55%) of this potential has been developed, and an additional 140 MW (4.1%) is under construction.
- Kerala has also identified 13 locations for pumped storage projects (PSPs) to harness the state's potential of more than 6 GW of PSP capacity.

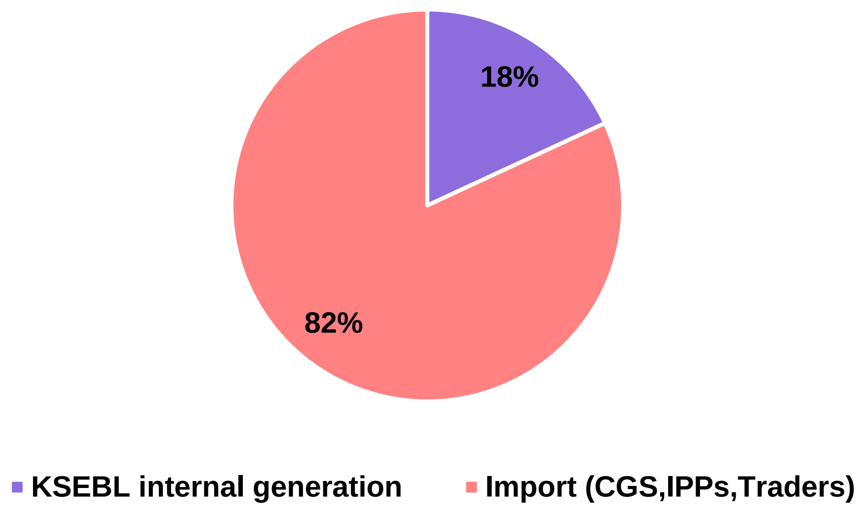
RE potential in state

Solar Potential	29,953 MW
Wind Potential	2,993 MW
Hydro Potential	3,378 MW

Source: MSM, PIB, CSTEP, The Hindu, MNRE, CEEW

Kerala has been largely relying on imports to meet its demand

Source wise power purchase in Kerala FY2024 (%)



KSEBL Internal Generation (MUs)

Source	FY 24
Hydro	5,600
Wind	1.21
Solar	53.13
Total	**5,654**

- Over the past five years (FY19-FY23), Kerala met ~30% of its demand using its own internal generation. However, this share declined drastically to 18% in FY24 due to a 34% drop in hydro power generation, from 8,538 MU to 5,600 MU.
- The total Kerala State Electricity Board Limited (KSEBL) generation and power purchase amounted to ~31,240 MU for FY24.
- 18% (5,654 MU) of the state energy demand was met by state-owned (KSEBL) generation and the remaining 82% (25,585 MU) was sourced through imports.

Note: CGS=Central Generating Stations; IPPs=Independent Power Producers; KSEBL=Kerala State Electricity Board Limited
Source: Power system statistics report by KSEBL

Kerala's energy requirement and peak demand have increased rapidly in the last 2 years

Kerala's energy requirement and supply

Financial Year	Energy Requirement (MU)	Energy Supplied (MU)	Energy Not Supplied (MU)	Energy Not Supplied (%)
FY 19	25,138	25,027	110.4	0.4%
FY 20	26,229	26,196	33	0.1%
FY 21	24,955	24,955	0	0.0%
FY 22	26,445	26,442	3	0.0%
FY 23	27,832	27,831	1	0.0%
FY 24	30,510	30,443	67	0.2%

Kerala's peak demand and peak met

Financial Year	Peak Demand (MW)	Peak Met (MW)	Demand Not Met (MW)	Demand Not Met (%)
FY 19	4,242	4,242	0	0.0%
FY 20	4,316	4,316	0	0.0%
FY 21	4,293	4,284	9	0.2%
FY 22	4,380	4,380	0	0.0%
FY 23	4,517	4,517	0	0.0%
FY 24	5,302	5,301	1	0.0%

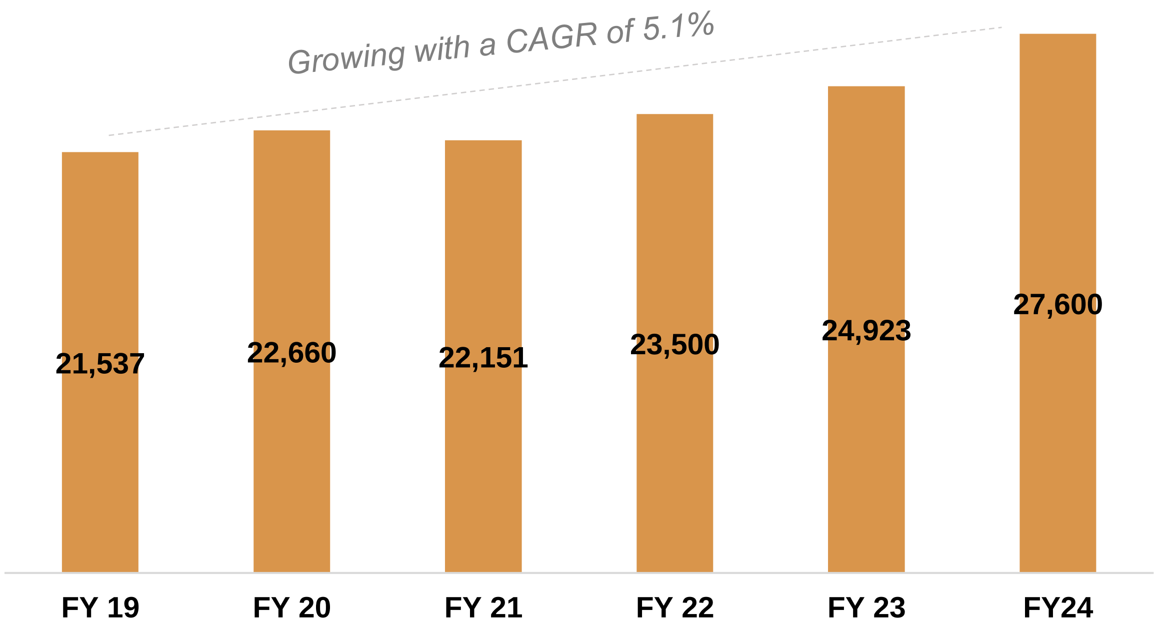
- Kerala's energy requirement and peak demand have increased over the years, with modest growth rates of 3.9% and 4.6%, respectively.
- The state was able to meet its energy requirements and peak demand with minimal shortfall between FY19 and FY24. However, it is important to note that a significant portion of this was met through imports.
- This high dependence on external sources highlights the need for developing self-reliance in Kerala's energy sector.

Source: India Climate and Energy Dashboard by NITI Aayog

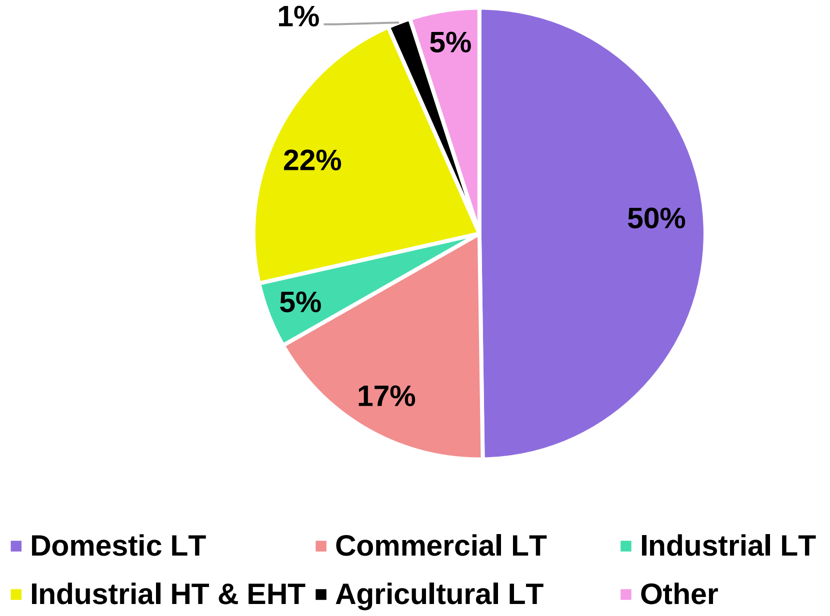
Demand side

The total electricity consumption in Kerala for the FY 24 was approximately 27,600 MU, primarily driven by the domestic sector

Electricity consumption over the last 5 years (MU)



Category wise electricity consumption in FY24 (percentage)



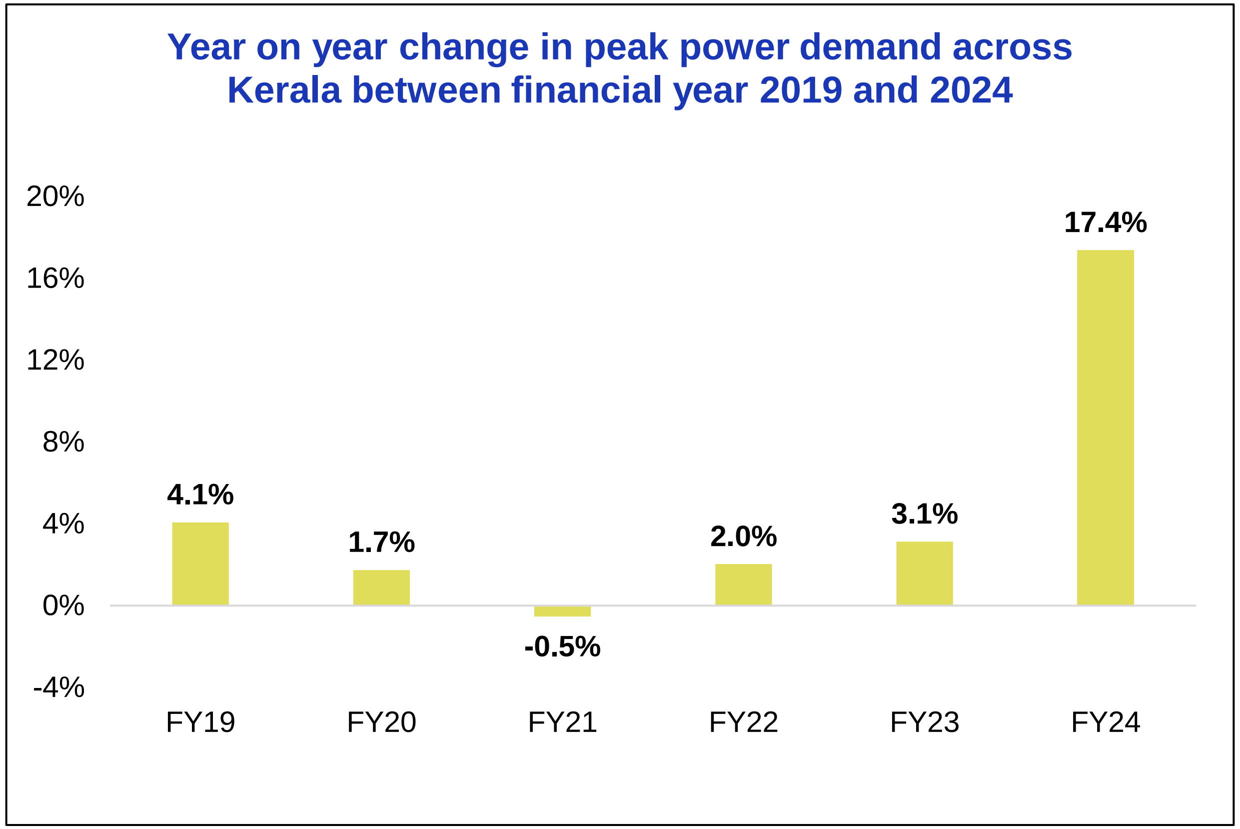
- The state did not experience a significant increase in demand during FY19 - FY23. However, the state saw a 10.7% rise in demand in FY24, primarily fueled by domestic consumption.
- Domestic consumption rose by ~11%, reaching 13,735 MU in FY24.
- The industrial category, encompassing low tension (LT), high tension (HT), and extra high tension (EHT) grew by 8.8% in FY24, while commercial category saw a growth of 7.8% in FY24.

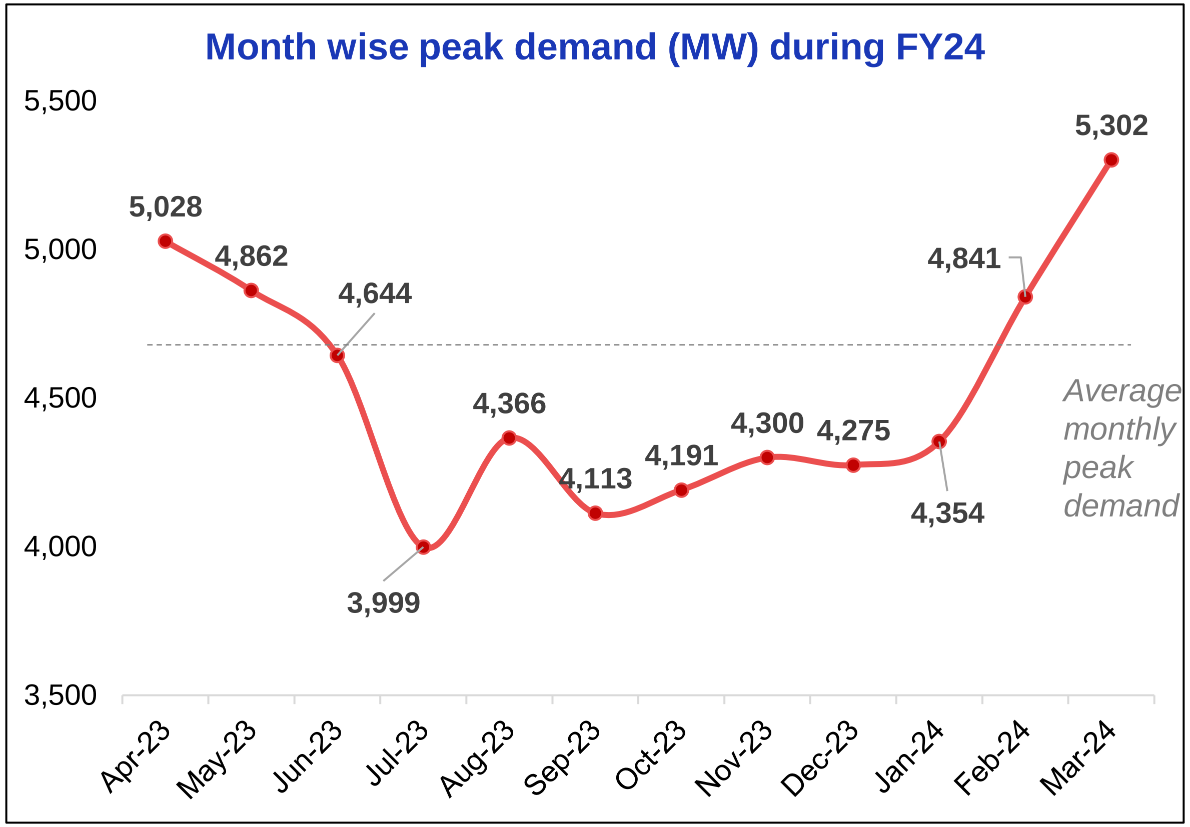
Note: Others include Public Lighting, Licensees and Railway Traction

Source: Power system statistics report by KSEBL

Demand side

Yearly peak demand increased with a CAGR of 4.6% in last 5 years, but grew 17.4% year on year to reach 5,302 MW in FY24



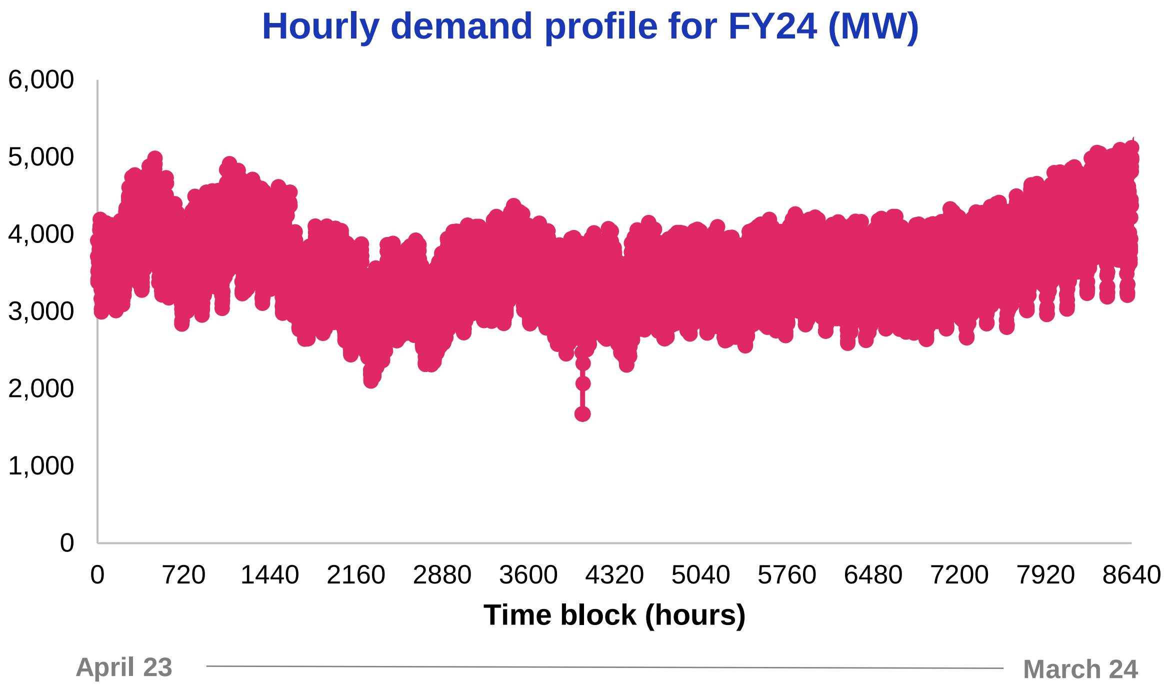


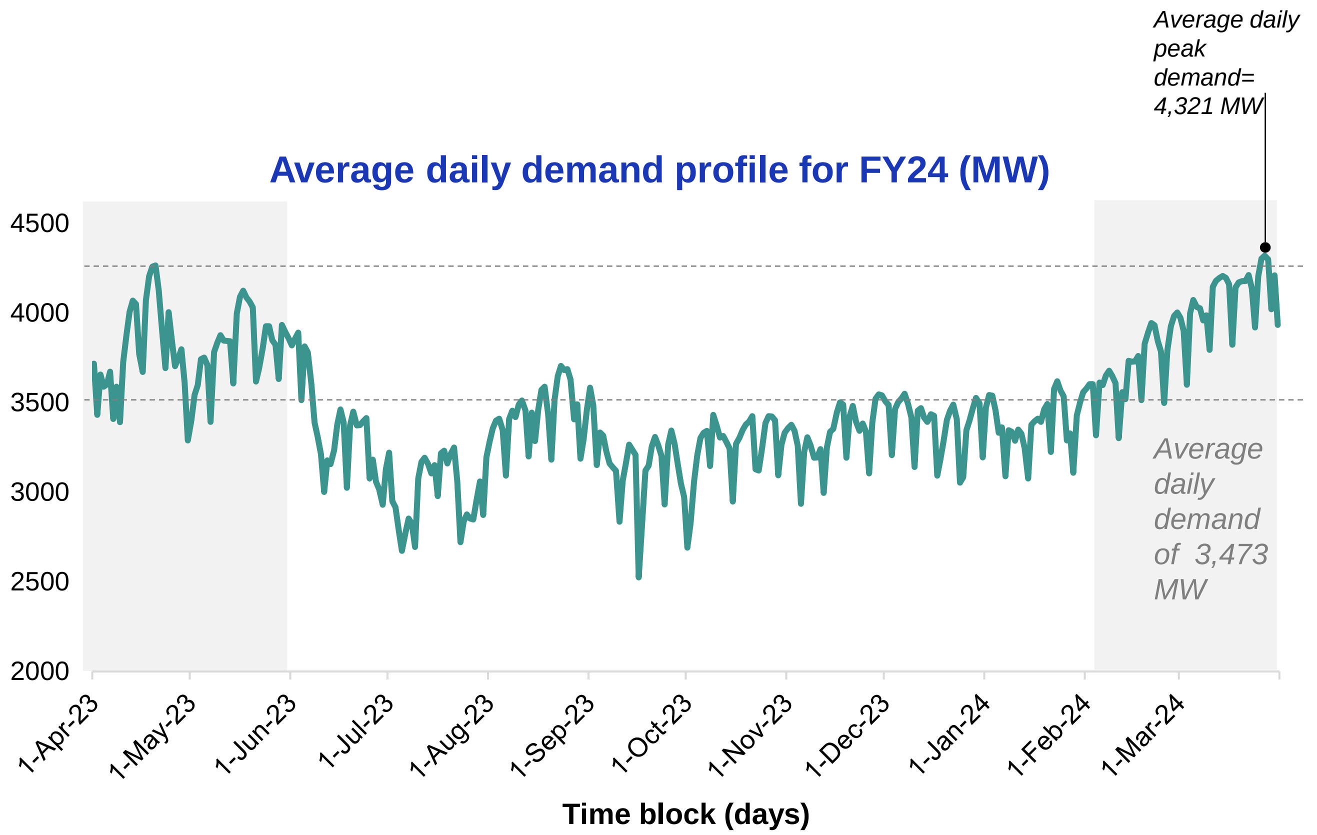
- During FY 2024, peak demand surged by 17.4% year on year, marking the highest increase in the past five years.
- The state experienced its highest peak demand during the months of February, March, April and May in FY24, above the average monthly peak demand of 4,523 MW during FY24.

Note: CAGR= Compounded Annual Growth Rate

Source: India Climate and Energy Dashboard by NITI Aayog

The state experienced its highest peak demand during the month of March in FY24

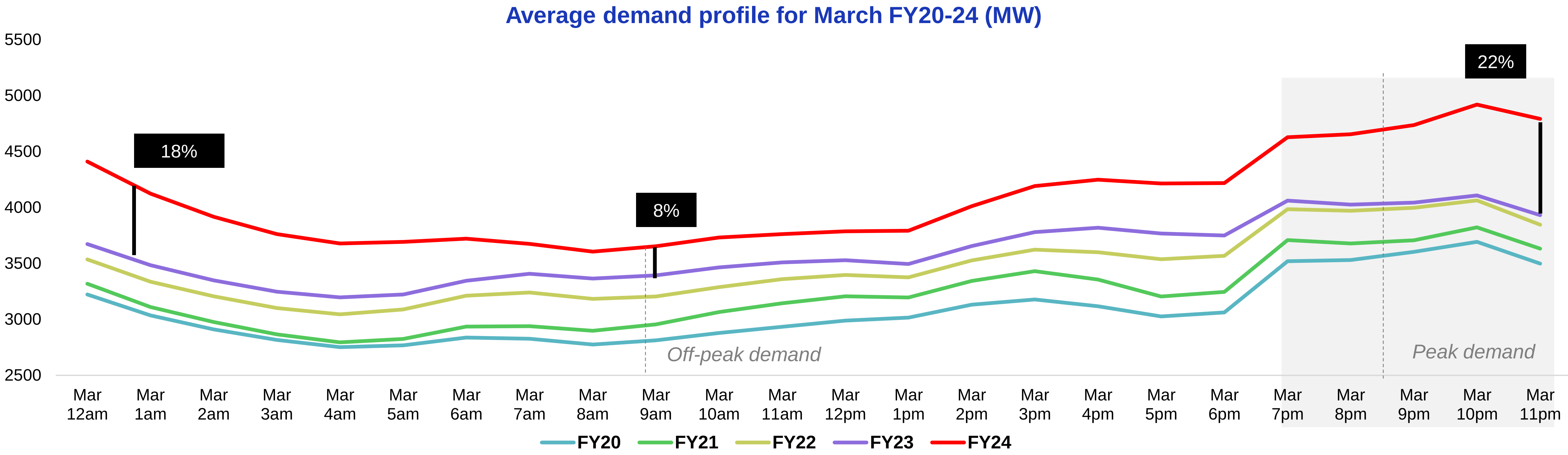




- Average daily peak demand saw an increase of ~ 20% during peak demand months compared to the average daily demand.

Source: India Climate and Energy Dashboard by NITI Aayog

The state is witnessing peak demand during late-evening hours



- The average monthly demand for March increased by 20% during peak hours (late evening @ 11:00 PM) and by 8% during off-peak hours (early morning @9:00 AM).
- Peak demand during late evenings lasts for about four hours, between 7 PM and 11 PM. Each year, this peak demand has become more prominent.
- The use of air conditioners (AC) is anticipated to be the major driver for the rise in peak demand in FY24.

Note: The average demand profile is estimated by averaging the demand for each hour across all days in the month of March. This method provides a representative hourly demand pattern for the entire month.

Source: India Climate and Energy Dashboard by NITI Aayog, KPMG Analysis

Key takeaways from the section

- Kerala relied heavily on imports to meet its energy demand.
- In the last two years, Kerala's electricity demand and peak demand have surged rapidly.
  - In FY24, the state saw a 10.7% rise in electricity demand, reaching 27,600 MU, primarily fueled by a substantial 10.9% increase in domestic consumption, which reached 13,735 MU.
  - Whereas in FY24, peak demand surged by an enormous 17.4% year on year.
- The state experiences highest peak demand during the months of February, March, April, and May,
  - The highest peak demand occurred in March FY24, reaching 5,302 MW in FY24
  - Peak demand is observed during late-evening hours, lasting for about four hours between 7 PM and 11 PM.

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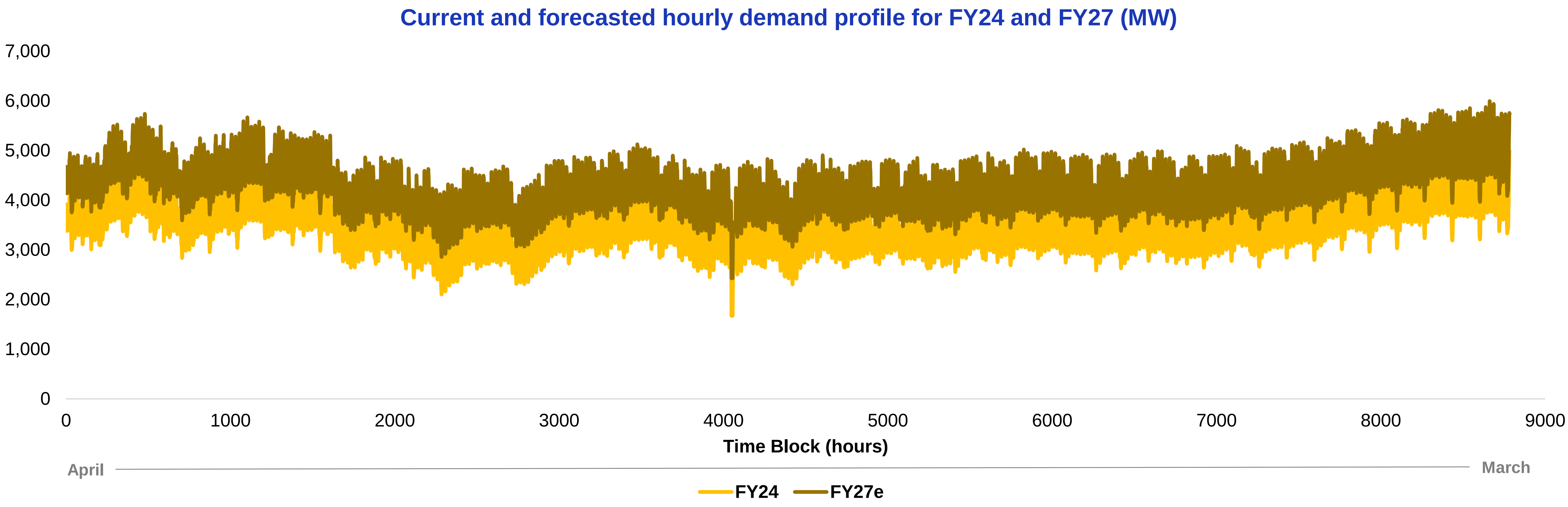
Future demand projections and storage potential by FY27

Kerala's energy demand is projected to grow consistently, with average hourly demand growing by ~750 MW by FY27 in a baseline scenario



- The average hourly demand throughout the year is expected to rise by ~20%, from 3,473 MW in FY24 to 4,222 MW in FY27.

Note:
- *It is assumed that Kerala's hourly demand curve profile will remain similar with growth.*
- *Detailed calculations are provided in Annexure*

Source: KPMG Analysis

Electric Vehicle (EV) charging, induction cookstoves, and AC usage are the three key factors contributing to the rising electricity demand in Kerala

Induction cookstoves:

The shift to induction cookstoves, which are more energy-efficient but electricity-dependent, has contributed to higher energy consumption.

2

Peak demand drivers

1

Electric Vehicle charging:

The rise in EV adoption has significantly increased the demand for energy due to the need for frequent charging.

3

AC usage

The growing use of air conditioners, especially during summer and monsoon months, leads to a substantial rise in energy demand.

Note: The following factors have been considered for peak demand projection:

- *3 hours of induction cookstove demand is considered, one hour each in morning, afternoon, and evening*
- *6 hours of EV charging is considered, starting at 9 PM and ending at 3 am*
- *7 hours of AC demand is considered, starting at 9 PM and ending at 4 am*

Source: Consultations with EMC

Kerala has witnessed a significant surge in EV deployment, with a 55% increase in registrations, from 52,241 in FY 23 to 80,913 in FY 24

1

Number of EVs registered in Kerala

EV Type	FY21	FY22	FY23	FY24
2W	779	11,411	44,447	65,204
3W	736	1,210	2,719	5,093
4W	678	2,246	5,025	10,390
Public service vehicles	0	13	50	95
Goods and Commercial Vehicles	0	2	0	131
Annual EV deployment	**2,193**	**14,882**	**52,241**	**80,913**

- 2W consistently dominate the market, with registrations skyrocketing from 44,447 in FY23 to 65,204 in FY24.
- In FY24, 2W accounted for 65,204 registrations out of the total 80,913 EV registrations, representing ~80% of overall EV sales. This highlights that 2W are the primary driver of EV adoption in the state.
- 4W registrations more than doubled from 5,025 to 10,390 in FY24 , while 3W saw a similar trend growing from 2,719 to 5,093 in FY24.

Source: Vahan Dashboard, KPMG Analysis

EVs are projected to contribute an additional energy demand of 339 MU by FY27

1

Projected Annual EV deployment in Kerala

EV Type	FY25	FY26	FY27
2W	91,286	127,800	178,920
3W	6,366	7,958	9,947
4W	13,507	17,559	22,827
Public service vehicles	109	126	144
Goods and Commercial Vehicles	144	159	174
Annual EV deployment	**111,412**	**153,601**	**212,013**
Cumulative EV deployment by FY27			**477,026**

Estimated energy demand projection for EV(in MU)

EV Type	FY25	FY26	FY27
2W	27	37	52
3W	19	23	29
4W	26	33	43
Public service vehicles	6	7	8
Goods and Commercial Vehicles	8	9	10
Annual EV demand (MU)	86	110	143
Cumulative EV demand (MU) by FY27			**339**

- Annual EV deployment in Kerala is anticipated to more than double over the next 3 years, reaching more than 200,000 units
- Annual EV deployment is projected to grow with a CAGR of 38%, increasing from 80,913 in FY24 to 212,013 in FY27.
- Annual EV energy demand is estimated to increase with a CAGR of ~29% over the next three years, contributing to an additional 339 MU by FY27

Note:
- *Energy demand has been estimated considering the average use of EV charging 6 hours a day.*
- *Due to lack of data, assumptions have been made to arrive at the EV energy demand number.*
- *Detailed calculations are provided in Annexure*

Source: Vahan Dashboard; 2W-financial express; 3W-LinkedIn and EV reporter; 4W- ToI; Public service vehicles-WRI and e-vehicle; Goods and commercial vehicles- Economic times; KPMG Analysis

Induction cookstoves are projected to contribute an additional energy demand of 340 MU by FY27

2

Estimated energy demand projection for induction cookstoves (in MU)

Particulars	FY25	FY26	FY27
No. of households (lakh)	106	108	110
Addition of induction cookstoves (lakh)	0.37	0.50	0.68
Annual induction cookstoves demand (MU)	81	110	149
Cumulative induction cookstoves demand by F27 (MU)	**340**		

- Energy demand from use of induction cookstoves is anticipated to grow by more than 80%, over the next 3 years.
- Energy demand from the use induction cookstoves is estimated to increase with a CAGR of 36%.

Note:

- *Energy demand has been estimated considering the average use of induction cookstoves 3 hours a day, considering 2kW load.*
- *Due to lack of data, assumptions have been made to arrive at the induction cookstoves energy demand number*

Source: CSTEP, KPMG Analysis

ACs are projected to contribute an additional energy demand of 1,208 MU by FY27

3

Estimated energy demand projection for AC (in MU)

Particulars	FY25	FY26	FY27
Addition of AC (lakh)	2	2.3	2.65
Annual AC demand (MU)	348	400	460
Cumulative AC demand by FY27 (MU)			**1,208**

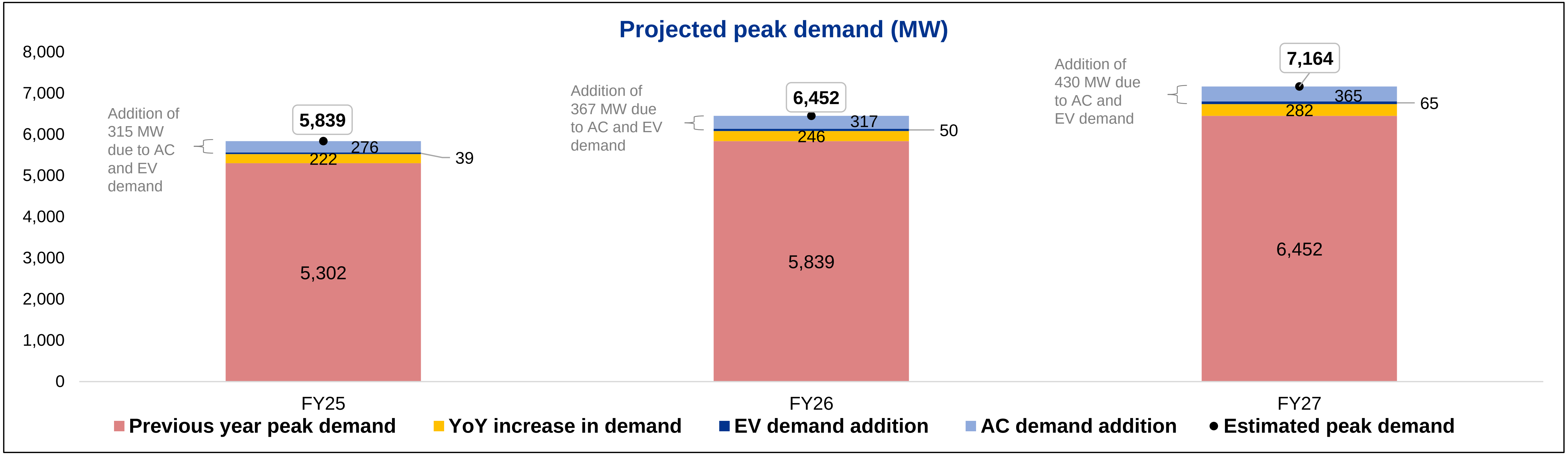
- Energy demand from the use of ACs is anticipated to be the major driver for the rise in energy consumption demand.
- Energy demand from ACs is estimated to increase with a CAGR of 15% over the next three years, whereas Kerala's energy consumption is growing at a CAGR of 5.1%.

Note:

- *Annual AC addition is assumed to grow at 15% year on year.*
- *Energy demand has been estimated considering the average use of AC for 7 hours a day and power consumption for a 1.5 tonne AC is assumed to be 1.2 kW.*
- AC usage has been considered for 6 months in a year.
- *Due to lack of data, assumptions have been made to arrive at the AC energy demand number*

Source: Consultations with EMC, ICRA, Indian express, KPMG Analysis

Estimated peak demand is likely to exceed 7,000 MW by FY27, driven by a surge in air conditioning demand

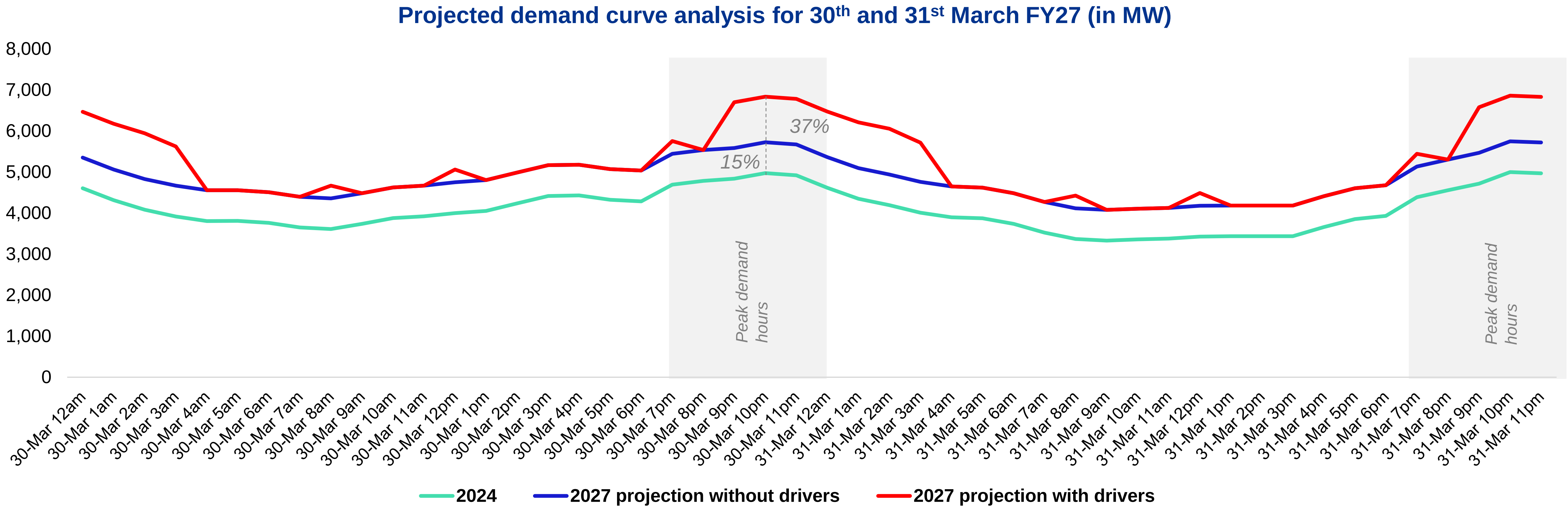


- Considering the impact of increased demand due to EV charging and AC usage, peak demand is expected to rise at a rate of 10.5%, which is significantly higher than the historical rate of 4.6%.
- Peak demand is projected to increase by over 1,800 MW in FY27, reaching 7,164 MW compared to FY24. This represents a year-on-year growth of ~530-700 MW over the next three years.
- Of this increase, ~1,100 MW in peak demand by FY27 is attributed to drivers such as ACs and EVs. Meanwhile, the normal growth of peak demand will contribute an additional 750 MW by FY27.

Note: Detailed calculations are provided in Annexure

Source: KPMG Analysis

The peak demand for FY27 with drivers is estimated to be 37% higher than in FY24



- The peak demand in FY27 is estimated to be 15% higher compared to FY24, without considering the impact of drivers. When accounting for drivers such as ACs and EVs, the peak demand is estimated to be 37% higher. This indicates that the surge in peak demand is primarily due to the growing use of ACs and EVs.

Note:

- *3 hours of induction cookstove demand is considered, one hour each in morning, afternoon, and evening*
- *6 hours of EV charging is considered, starting at 9 PM and ending at 3 am*
- *7 hours of AC demand is considered, starting at 9 PM and ending at 4 am*

Source: KPMG Analysis

Battery energy storage systems is more suitable than PSP, considering Kerala storage needs

BESS offer several advantages over PSP when considering Kerala's energy storage need:

1 Long gestation periods

- PSPs require over five years to develop, making them unsuitable for meeting peak demand by FY27. On the other hand, BESS provide a swift, efficient, and commercially viable alternative to address energy storage needs within the required timeframe.

2 Aligning with Kerala's storage requirement characteristics till FY27

- Kerala faces a late evening peak demand lasting around four hours, a pattern expected to persist until FY27. This consistent demand aligns perfectly with the strengths of BESS, which excel in short-duration energy storage. With their rapid response and grid stabilization capabilities, BESS emerges as a highly effective and practical solution to meet Kerala's critical energy requirements during these peak hours.

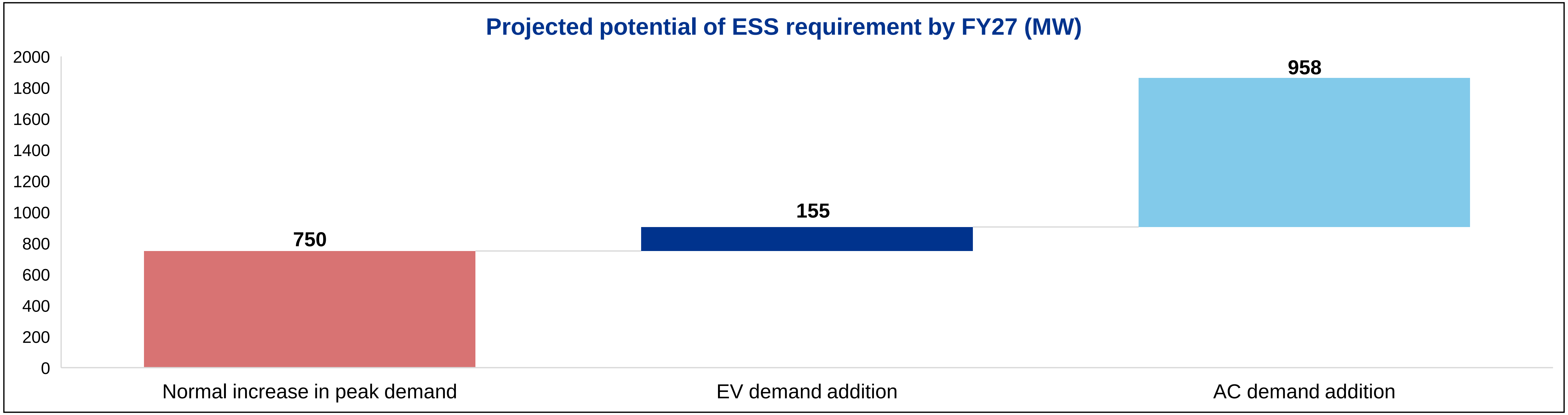
3 Suitability for short-duration storage upto 4 hours

- For short-duration storage and rapid energy provision, battery storage systems (BESS) are a more suitable option due to their high energy density, fast response times, and ability to provide ancillary services like frequency regulation and peak demand management.

KSEBL plans to develop two PSPs with a combined capacity of 130 MW. However, these projects are still in the early stages of planning and approval, with funding and implementation strategies yet to be finalized. Given the current timeline, these projects are unlikely to become operational before FY30. For immediate and short-duration requirements, BESS offer a more practical and efficient solution.

Source: Hindu

With an estimated potential of ~1.8 GW and 4 hours of BESS capacity, Kerala's projected peak demand can be met by FY27



- The increase in AC demand is expected to be the primary contributor to the rise in peak demand by FY27, accounting for ~ 50% of the total increase.
- Considering the peak hours demand of 4 hours, the **estimated potential for battery energy storage system (BESS) capacity will be ~7.4 GWh by 2027.**
- Going forward, trend indicate that the duration of peak hours will increase from the current 4 hours (7 pm - 11 pm) to ~6 hours (7 pm - 1 am). Consequently, storage capacity will need to be ~11.1 GWh, considering a duration of 6 hours, which supports the case for PSP.

Note: Detailed calculations are provided in Annexure; The normal increase in peak demand is the amount of increase in peak demand based on data from previous years; PSP=Pump Storage Projects

Source: KPMG Analysis

The Levelized cost of storage (LCoS) of lithium-ion battery storage for a 4-hour duration comes out to be INR 5.20 per kWh

BESS parameters

Input	Value	Unit
Battery Technology - Chemistry	Lithium Ferro Phosphate (LFP)	#
BESS Discharge Duration	4	Hours
Daily usage cycle	1	Cycle
Project life	12	Years

Assumptions

Input	Value	Unit
BESS cost	110	$/kWh
Annual degradation	2.5	%
Round trip efficiency	85	%
Life cycle	7,000	Cycles
Depth of Discharge	95	%

- Considering the charging cost for BESS at INR 2.6 per kWh, the total cost of BESS plus charging will be ~INR 7.8 per kWh.
- **The quantum of investment required to deploy ~7.4 GWh of storage by FY27 will range between ~INR 8,000-8,900 Cr.**

Note: Debt is considered 70% and equity is considered 30%; BESS=Battery Energy Storage System

Source: Institute for Energy Economics and Financial Analysis (IEEFA), PV Tech, KPMG analysis

BESS LCoS varies significantly depending on duration and cycles per day

BESS cost variation based on cycles and duration

All values in INR/kWh		Cycles	
		1 Cycle	2 Cycle
Duration	2 hour	~5.8	2.5-3 (Market)
	4 hour	~5.2 (Aligned with Kerala requirement)	~2.6

- The discharge duration and cycles per day are two critical factors that impact the LCoS.
- Discharge duration refers to the amount of time a storage system can provide energy once fully charged, while cycles per day indicate the number of times the system is charged and discharged within a single day.
- LCoS decreases as both discharge duration and cycles per day increases.

Note:

- *LCoS cost shown are estimates and without Viability Gap Funding (VGF)*
- *Modelled LCoS for a 2-hour 2 cycle system is INR 2.9 per kWh*
- *BESS systems currently provide 2-4 hours of storage, which can be options to meet the requirement.*
- *LCoS= Levelized Cost of Storage*

Source: Lazard, KPMG Analysis

Kerala has largely relied on STOAs, SWAP agreements, and Power Exchanges to meet its electricity demand in FY24

Supply and cost analysis of various imports

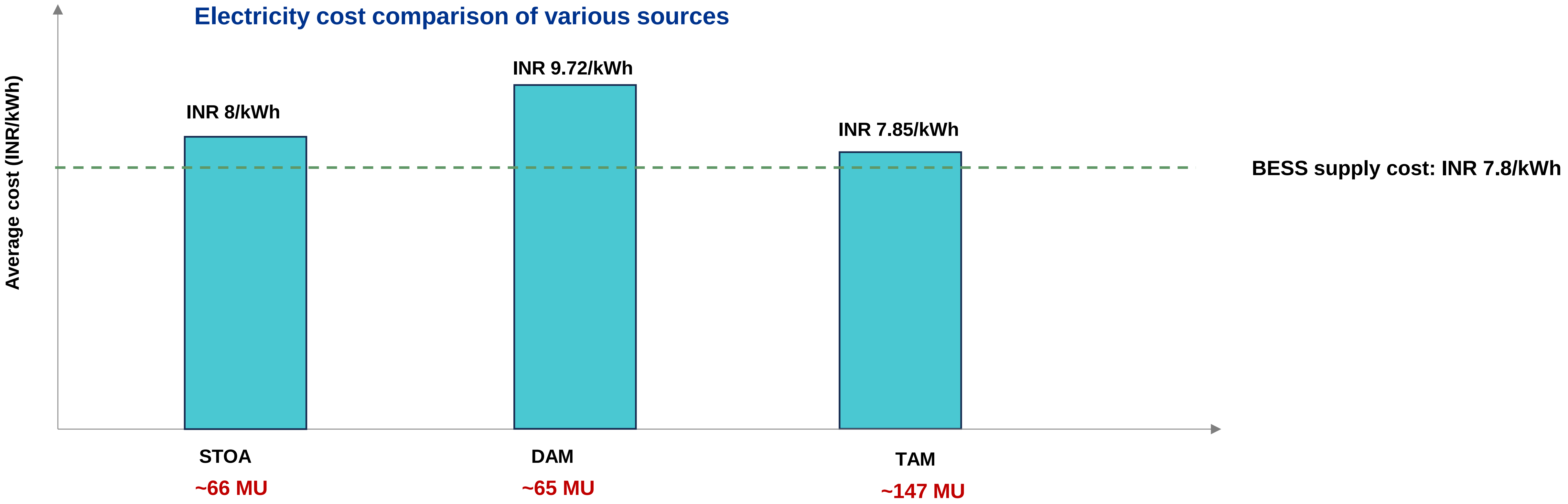
Category	Source of Power	Electricity supplied in FY23 (MU)	Electricity supplied in FY24 (MU)	Avg cost of energy received in FY24 (Rs/kWh)
Trader	STOA	968	2,211	5.43
Exchanges	TAM	62	972	7.55
	DAM	139	834	5.5
	RTM	83	1,772	4.98
Discom Agreements	SWAP	231	844	-
Total		**1,484**	**6,633**	

- Kerala's supply from STOAs, Power Exchanges, and SWAP agreements rose sharply between FY23 and FY24, from ~1,480 MUs in FY23 to ~6,630 MUs in FY24.
- These sources supplied an excess of ~970 MU in FY24 over FY23 during the peak demand months (February, March, April, and May).

Note: STOA= Short-Term Open Access; DAM=Day-Ahead Market; TAM=Term-Ahead Market

Source: KSEBL Truing Up of Accounts for Year 2023-2024, CEA

~300 MUs of electricity supplied in FY24 was more expensive than the estimated BESS supply cost of INR 7.8 per kWh



- BESS prices are expected to slightly decrease or remain stable in the near future, whereas the cost of supply from other sources (markets, imports, etc.) will be increasing year on year, making BESS more appealing.
- By 2027, Kerala can mitigate the effect of rising electricity demand and import costs by shifting towards BESS, leading to significant cost savings.

Note: Only those sources are shown whose cost of electricity per kWh is higher than BESS plus charging, which is INR 7.8 per kWh; STOA= Short-Term Open Access; DAM=Day-Ahead Market; TAM=Term-Ahead Market

Source: KPMG Analysis

Scenario analysis of two different BESS systems: 4-hour, 1-cycle and 2-hour, 2-cycle

Parameter	Scenario 1 (Meeting complete peak)	Scenario 2 (Meeting half peak)
Peak duration met	4 hours	2 hours
Storage requirement	~7.4 GWh	~3.7 GWh
Number of cycle	1	2
Upfront cost	INR 8,000-8,900 Cr	INR 4,500-5,000 Cr
BESS project life	12-16 years	8-10 years
Levelized Cost of Storage (LCoS)	~INR 5.2 per kWh	~INR 2.9 per kWh
BESS supply cost	~INR 7.8 per kWh	~INR 5.5 per kWh
Economic potential for shifting electricity by FY27	300 - 400 MU	1,500 - 1,850 MU
Remarks	Though the upfront cost and LCoS in scenario 1 are higher compared to scenario 2, Kerala will be well-positioned to meet the peak demand of 4 hours. This scenario does not incur replacement cost. In the future, due to the rise in AC usage and EV charging, the peak demand duration will likely increase, making this scenario even more realistic.	This scenario requires less upfront cost and has a lower LCoS compared to scenario 1, making it possible to shift a sizeable amount of expensive electricity which was imported through STOA, DAM, and TAM in FY24. **However, due to the increased cycle usage, the lifespan of the BESS will reduce, resulting in replacement costs.** **Also, Kerala won't be able to meet the complete peak demand. The state will also need to utilize the second cycle during the daytime. This approach will not be sufficient to fulfill the increasing peak demand in the near future.**

Note: STOA= Short-Term Open Access; DAM=Day-Ahead Market; TAM=Term-Ahead Market

Source: KPMG Analysis

NA | Favorable | Not Favorable

Comparison of projections between the present study and CSTEP (1/2)

Parameter	CSTEP as of FY30	Present study as of FY27	Remarks
Peak demand	~5,500 MW	~7,100 MW	• CSTEP considered the impact of EVs and induction cookstoves to predict the final energy consumption by FY2030. Based on this, the peak demand was estimated. • CSTEP did not consider the impact of AC usage on the rising peak demand by FY30. • The present study estimates the peak demand based on historical growth, combining the increased demand from EV charging and AC usage. • The present study analyzes that peak demand is likely to increase by over 1,800 MW by FY27 compared to FY24 (i.e., 5,300 MW), reaching more than 7,000 MW.
Estimated storage capacity	2.1 GW	1.85 GW	• CSTEP conducted a storage analysis spanning 8,760 hours, which allowed them to identify instances of under-generation and over-generation. Through this, CSTEP estimated the optimal storage capacity required. • CSTEP under the high-RE scenario found a significant demand-supply gap on the peak day, with a maximum deficit of ~2,077 MW projected by FY30. • The present study estimates the potential for storage capacity by FY27 by analyzing the peak demand duration and the increase in peak demand. • The present study analyzes that an additional peak demand of ~1.8 GW by FY27 can meet Kerala's projected requirements.

Note: CSTEP=Center for Study of Science, Technology and Policy

Comparison of projections between the present study and CSTEP (2/2)

Parameter	CSTEP as of FY30	Present study as of FY27	Remarks
EV electricity demand	884 MU by F30 (364 MU by FY27)	339 MU by FY27	• CSTEP assumed a slower growth rate to predict the annual EV deployment numbers. • CSTEP estimated the energy demand for various types of EVs, considering moderate levels of their energy consumption and typical daily travel distances. • The present study assumes a moderate growth to predict the annual EV deployment numbers. • The present study estimates the energy demand for various types of EVs, considering practical levels of energy consumption and typical daily travel distances.
Induction cookstoves electricity demand	438 MU by F30 (172 MU by FY27)	340 MU by FY27	• CSTEP assumed an average use of induction cookstoves of 1 hour per day. • The present study assumes an average use of induction cookstoves of 3 hours per day, at different times of the day.

Note: CSTEP=Center for Study of Science, Technology and Policy

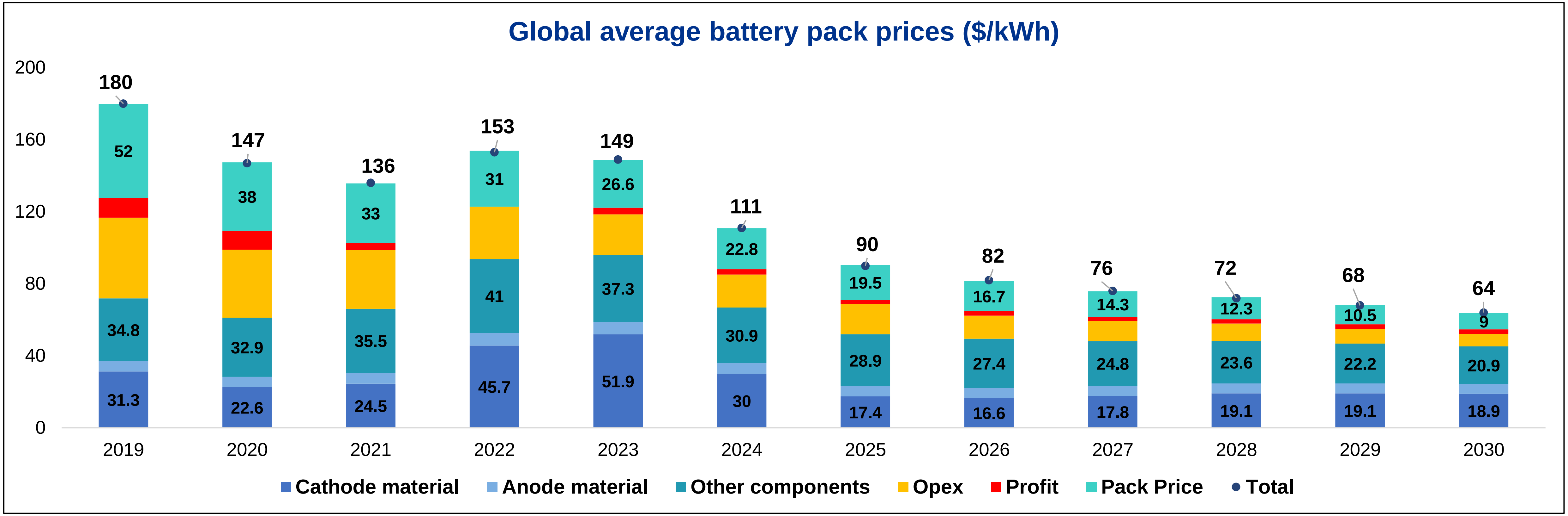
Key takeaways from the section

- The rising electricity demand in Kerala is primarily driven by factors such as EV charging, induction cookstoves, and AC usage.
- Peak demand is expected to increase significantly, exceeding 1,800 MW by FY27 compared to FY24, reaching a total of 7,164 MW.
  - Out of this increase, around 1,100 MW is attributed to the growing use of ACs and EVs, while the remaining 750 MW comes from normal growth in peak demand.
- Considering the four-hour peak demand duration, the estimated storage capacity requirement will be around 7.4 GWh by 2027.
  - The LCoS for lithium-ion battery storage with a four-hour duration is estimated to be ~INR 5.2 per kWh.
  - The investment needed for deploying ~7.4 GWh of storage by FY27 is projected to range between ~INR 8,000 and 8,900 Cr.

03

Developments in the Energy Storage System sector

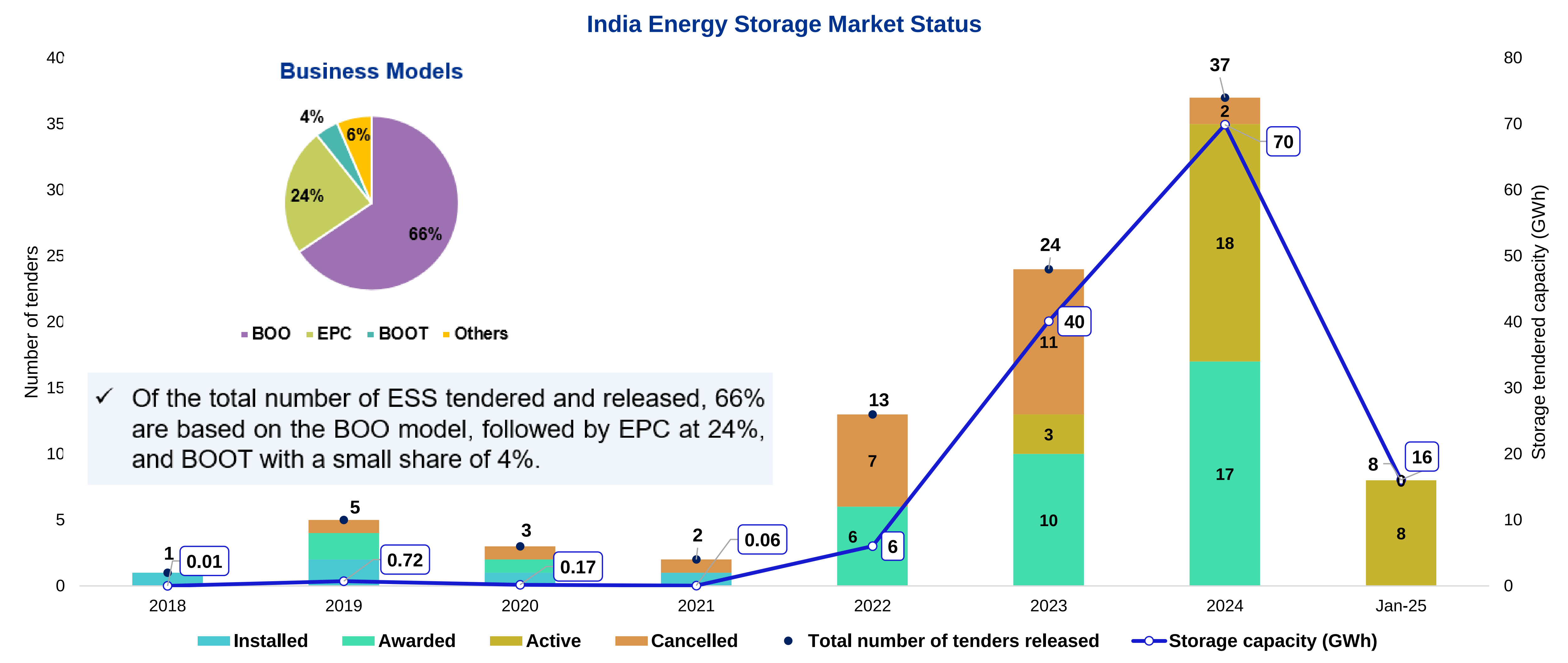
Battery price forecasts continue to fall



- Battery costs globally have decreased ~90% in last decade and this cost reduction trend is expected to continue.
- Global average battery prices could fall towards $80/kWh by 2026, amounting to a drop of almost 50% from 2023.
- Manufacturing overcapacity and the cost of critical minerals have driven significant battery price reductions, which are further accelerated by continuous technology and process improvements.

Source: Goldman Sachs, 2024- 2030 are forecasts

Energy storage system is experiencing significant growth and market activity in India since 2024



✓ Of the total number of ESS tendered and released, 66% are based on the BOO model, followed by EPC at 24%, and BOOT with a small share of 4%.

Note: ESS=Energy Storage System; BOO= Build Own Operate; EPC= Engineering Procurement Construction; BOOT= Build Own Operate Transfer

Source: Tender nodal agency websites, JMK research & analytics, press releases, compiled by KPMG

A total of 133 GWh of ESS capacity tenders have been released, of which 54 GWh have been awarded, while 43 GWh are in the open tendering process

Number of ESS tendered	93
ESS Capacity Awarded	~54 GWh
ESS Capacity Active	~43 GWh

ESS Capacity Tendered	~133 GWh
PSP Capacity Awarded	~40 GWh
PSP Capacity Active	~20 GWh

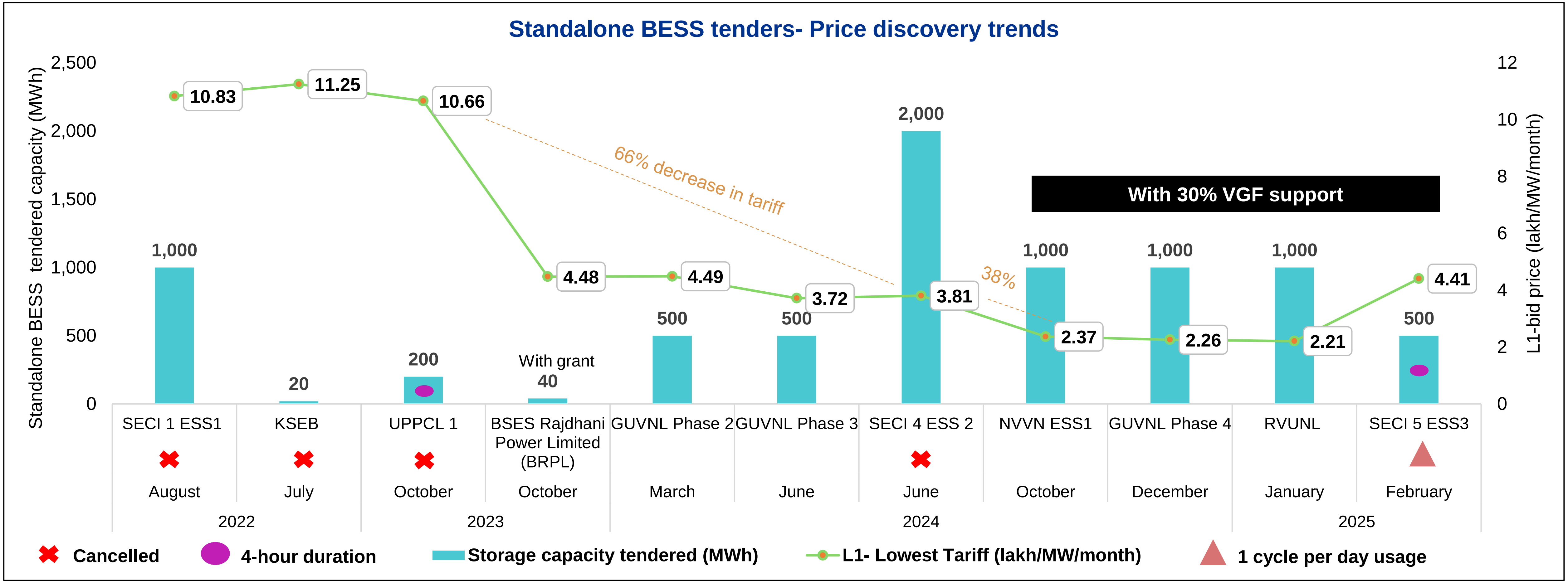
BESS Capacity Awarded	~14 GWh
BESS Capacity Active	~23 GWh

- In February 2024, Solar Energy Corporation of India Limited (SECI) unveiled India's largest solar-battery project (120 MWh)
- In June 2024, SECI issued 1,000MW/2,000MWh standalone BESS tender; India's biggest till date
- In October 2024, NTPC Vidyut Vyapar Nigam Limited (NVVNL) issued 1 GWh of standalone BESS tender with VGF support. This tender was recently awarded at INR 2.37-2.38 lakhs/MW/month
- In December 2024, SECI's 2 GW solar with 4 GWh (1 GW * 4 hour) BESS finds tariff discovery of INR 3.52/kWh
- In January 2025, Rajasthan Rajya Vidyut Utpadan Nigam Limited (RVUNL) 500 MW/ 1000 MWh standalone BESS tender with VGF support; awarded at record low tariffs of INR 2.21 lakhs/MW/month

Note: Energy Storage System; VGF=Viability Gap Fund

Source: Tender nodal agency websites, JMK research & analytics, press releases, compiled by KPMG

The tariff discovered for standalone BESS tenders has seen an 80% drop in a 3-year timeframe due to decrease in global battery prices

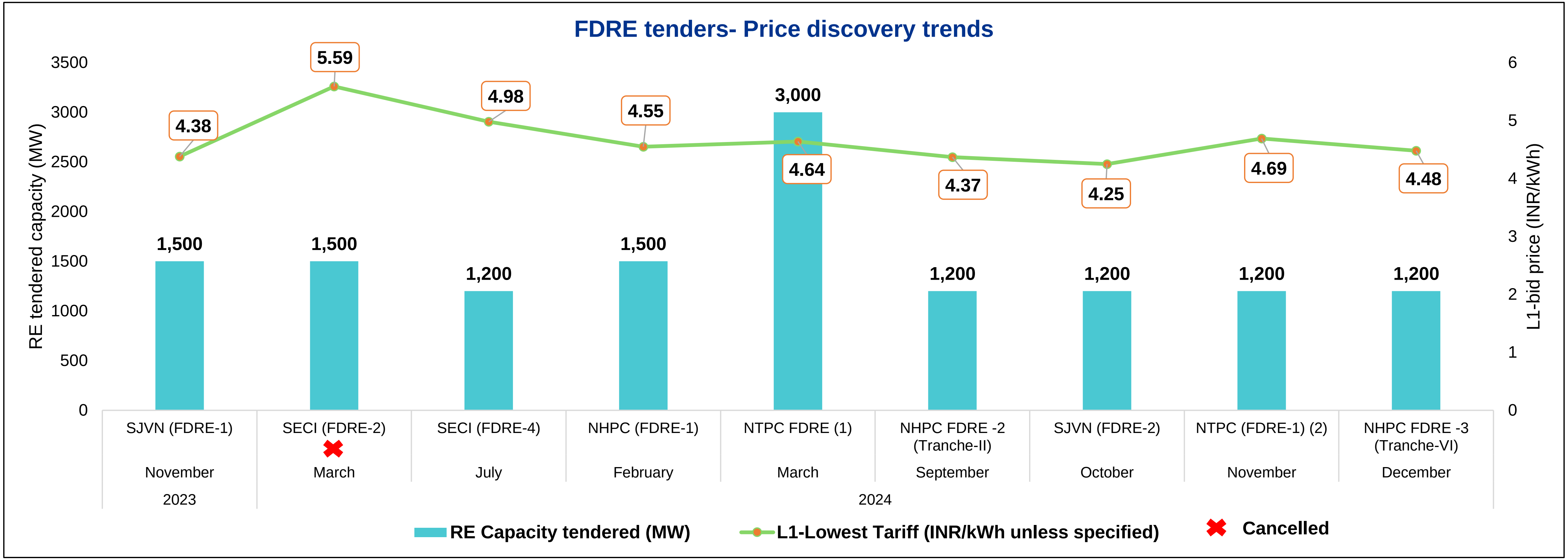


- All these awarded standalone tenders were based on the BOO model, except SECI ESS1 and BRPL, which were based on the BOOT model.

Note: The tariff that has been discovered is for 2 hours and 2 cycles per day except UPPCL 1 and SECI 5 ESS3 ; BOO= Build Own Operate; BOOT= Build Own Operate Transfer

Source: Tender nodal agency websites, JMK research & analytics, press releases, compiled by KPMG

The tariff discovered for FDRE tenders has consistently ranged between INR 4 and 4.5 per kWh



- All the awarded firm dispatchable renewable energy (FDRE) tenders were based on the BOO model, except SECI FDRE-2, NHPC FDRE-1 and SJVN FDRE-2, which were based on the BOOM model.

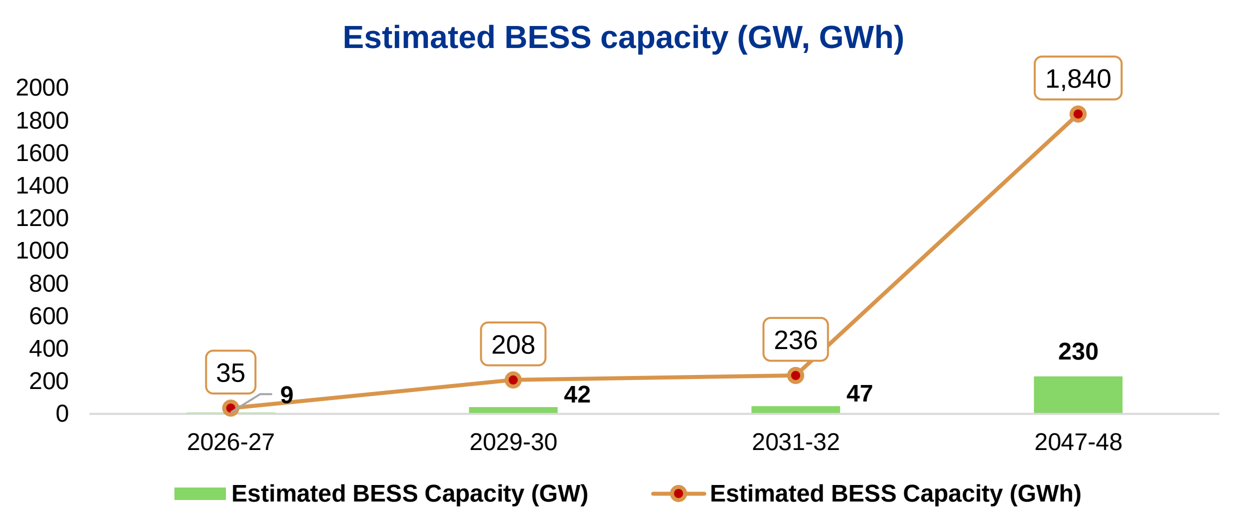
Note: SJVN=Satluj Jal Vidyut Nigam; BOOM=Build Own Operate Maintain; BOO= Build Own Operate

Source: Tender nodal agency websites, JMK research & analytics, press releases, compiled by KPMG

BESS capacity is expected to reach 1,840 GWh by 2047-48 with INR 350,000 Cr investment upto 2032

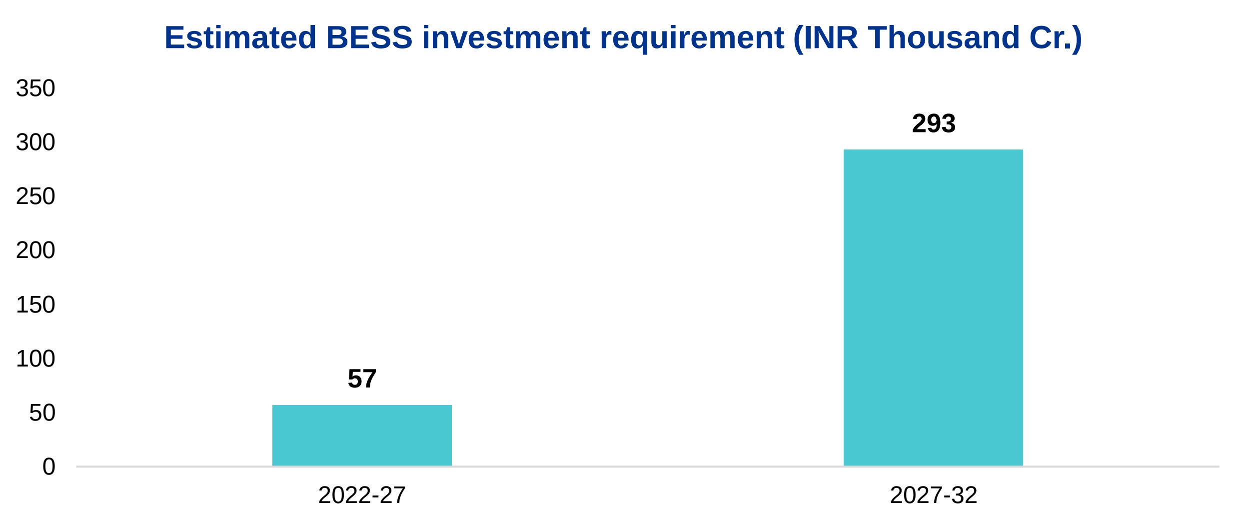
BESS deployment has been supported by key policy and regulatory interventions:

- Development of Energy Storage Obligations
- Guidelines for FDRE procurement mandating storage deployment
- National framework for promoting Energy Storage Systems
- Viability Gap Funding for BESS projects



Drivers for BESS adoption

- **Sharp reductions in cost**
- **Improvements in technological capabilities**
- **Need to integrate RE generation in grid**
- **Supportive policy and regulatory framework**
- **Ecosystem of developers/ system integrators**
- **Strong demand side push through FDRE and RTC tenders**

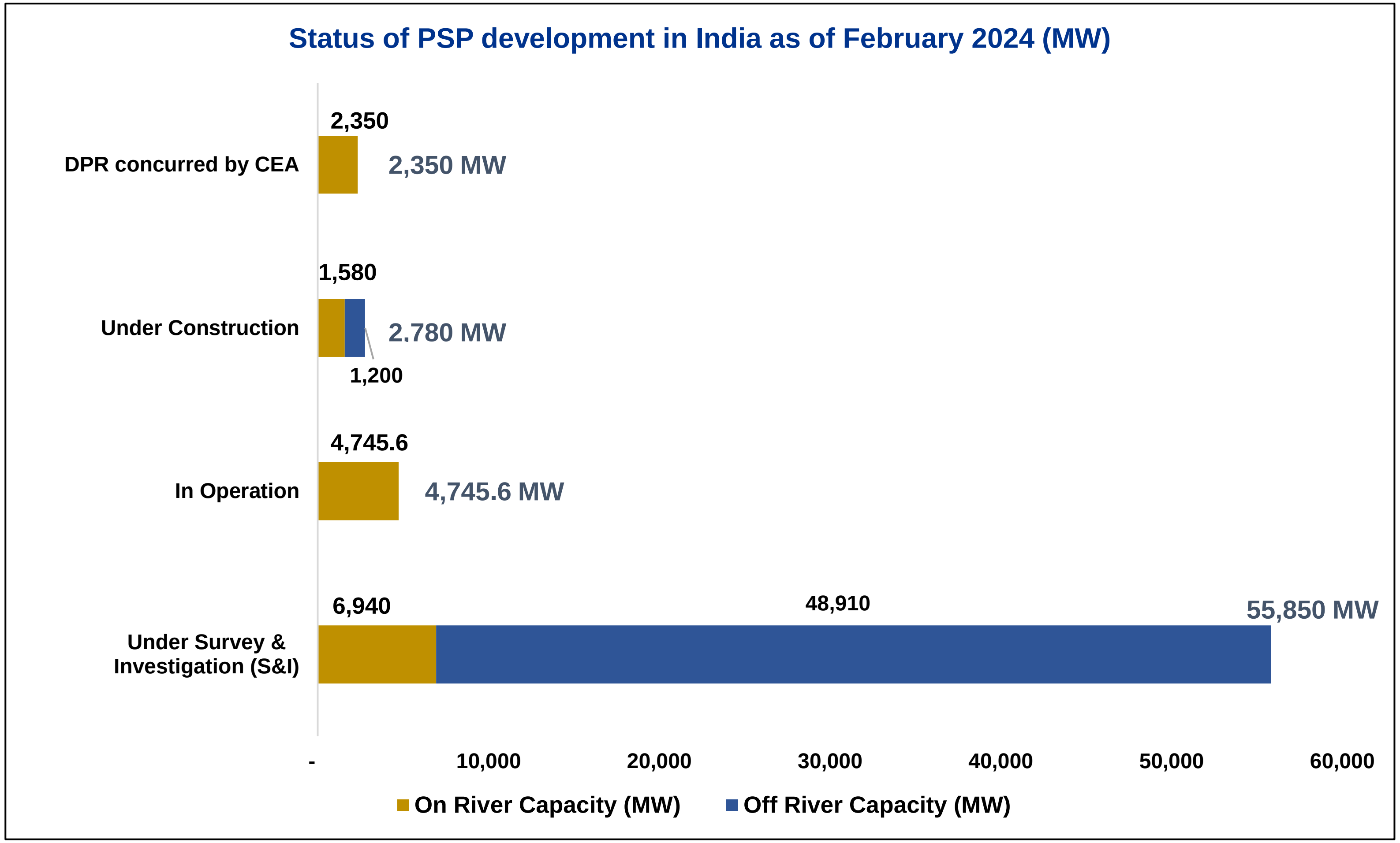


Note: RTC= round the clock

Source: National framework for promoting Energy Storage Systems, Ministry of Power (MoP), Government of India

PSPs are seeing renewed interest in India, with public and private participation leading to a 65 GW+ project pipeline

- PSPs were first deployed in India ~50 years ago.
- Both closed loop (off-river) and open loop (on-river) projects are feasible.
- A wide variety of use cases are enabled by PSPs, including peak load shaving, energy arbitrage, ancillary services, RE smoothing, and seasonal storage, amongst others.
- India has significant PSP potential, with feasible capacity estimated to exceed 170 GW.

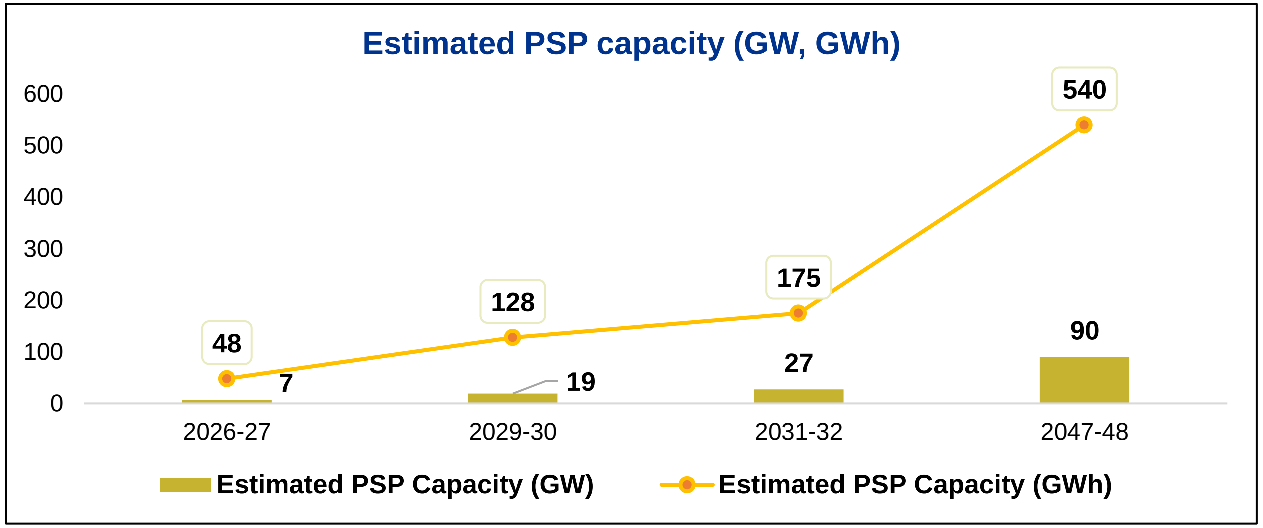


Source: Status of Pumped Storage Development in India, Central Electricity Authority (CEA), February 2024

PSP capacity is expected to reach 90 GW by 2047-48 with INR 129,000 Cr investment upto 2032

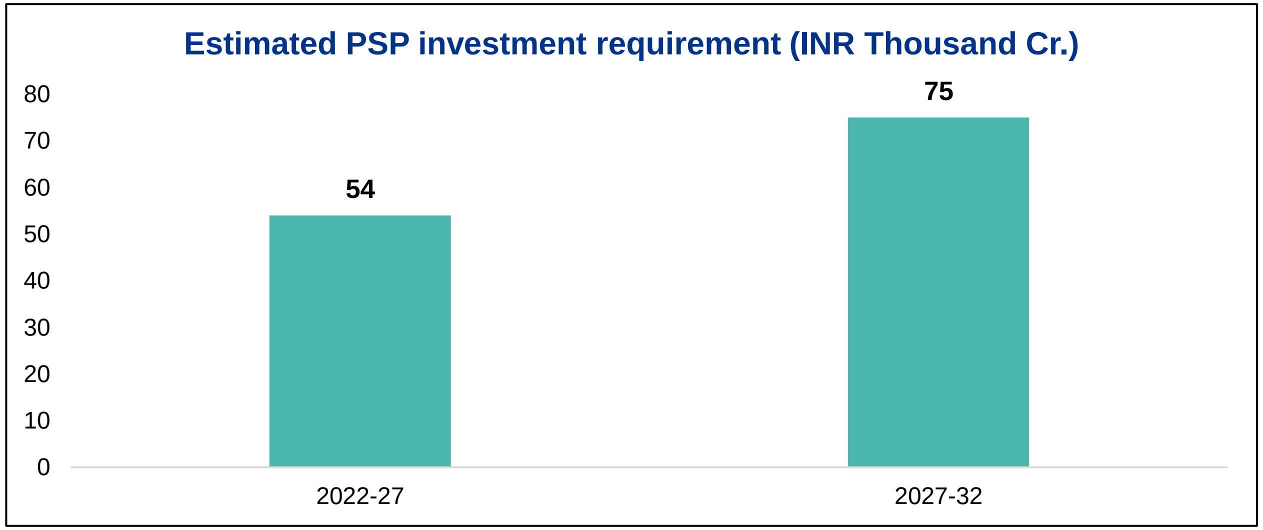
PSPs have been supported by key policy and regulatory interventions:

- Hydro & Energy Storage Obligations
- Waiver of ISTS charges
- Budgetary support and tax benefits
- Long-term loans from PFC, REC Limited etc.
- Select regulatory exemptions
- State level policy incentives



Drivers for PSP adoption

- **Enables long duration energy storage use cases**
- **Availability of suitable project locations**
- **Technological maturity**
- **Cost effective for long duration storage**
- **Supportive policy and regulatory framework**
- **Demand side push through dedicated PSP tenders**



Note: ISTS=Inter State Transmission System, PFC= Power Finance Corporation

Source: National framework for promoting Energy Storage Systems, Ministry of Power (MoP), Government of India

When comparing PSPs and BESSs, several factors come into play

Parameter	Pump storage projects	Battery energy storage system
Gestation period	Longer, 5-7 years	Shorter, 1-2 years
Land requirements	Higher, geographic restrictions	Lower, Modular in nature
Upfront cost	~INR 0.8-0.9 Cr per MWh	~INR 0.9-1.1 Cr per MWh
Maturity	Highly mature, commercialized	Evolving, partially commercialized
Topography	Dependent on-site characteristics	Agnostic
Duration & Discharge	Longer, 6-8 hours	Shorter, 2-4 hours
Efficiency	75-80%	85-90%
Project Life	Long, often more than 40 years	Short, around 8-12 years
Levelized Cost of Storage (LCoS)	~INR 4 - 6 per unit, unlikely to reduce further	~INR 2.5 - 5.5 per unit*, likely to reduce further

- PSP excel in long-duration storage over longer lifespans, while BESSs offer faster deployment and greater location flexibility.
- PSP currently have a cost advantage, especially for long-duration storage, BESS costs are also declining sharply.
- As observed in slide 26, peak demand in Kerala may increase from 4 hours to 6 hours in near future, leading to increased PSP deployment potential.

*Note: * depending on cycles per day, LCoS is usually lower for higher cycles usage per day*

NA | Highly Favorable | Moderate | Not Favorable

Source: Care edge ratings

Key takeaways from the section

- Globally, battery costs have dropped by about 90% over the last decade, and this trend is expected to continue.
- By January 2025, ~ 133 GWh of storage-linked tenders had been issued, with 93 tenders released. Out of this total tendered ESS capacity, 54 GWh have been awarded, and 43 GWh are still active.
  - The tariff for standalone tenders has decreased by 80% in three years due to falling global battery prices.
  - In January 2025, the RVUNL awarded a 500 MW/1000 MWh standalone BESS tender with VGF support at record-low tariffs of INR 2.21 lakhs/MW/month.
  - For FDRE tenders, the tariff has consistently ranged between INR 4 and 4.5 per kWh.
- PSPs are beneficial for long-duration storage over extended lifespans, while BESS offer quicker deployment and greater location flexibility.
- Currently, PSPs have a cost advantage, especially for long-duration storage, but BESS costs are also decreasing rapidly.

04

Analysis outcomes and preliminary recommendations

Summary of analysis

Peak demand drivers

- EV charging
- AC usage
- Peak demand drivers accounting for ~1,100 MW increase in peak demand out of 1,800 MW.

Projected peak demand by FY27

Kerala's peak demand is projected to reach more than ~7,000 MW.

Potential of storage

The peak demand duration in Kerala last about four hours, with a potential storage capacity of 7.4 GWh.

Investment required

The investment to deploy 7.4 GWh of storage capacity by FY27 is projected to range between ~INR 8,000 to 8,900 Cr.

Assessment of different ESS technologies

- PSP is ideal for long-duration storage due to extended lifespans and cost-effectiveness.
- BESS offer quick deployment and location flexibility, making them suitable for short-term storage solutions with rapidly declining costs.

By carefully considering these factors, KSEBL can make informed decisions on whether to opt for a CAPEX or OPEX model that best aligns with their financial strategy and operational needs.

Quantitative considerations

	Description	CAPEX	OPEX	Comments
Upfront cost requirement	Depending on the model selected, Kerala may have to incur an upfront cost for deployment of BESS capacity.	An upfront cost, inclusive of EPC charge, would have to be incurred by Kerala for self-deployment of BESS. In order to meet the estimated storage potential by FY27, this cost would range from 8,000 Cr to 8,900 Cr to meet the entire additional demand of ~7.4 GWh upto FY27, based on current BESS price trends.	No upfront cost would be incurred by Kerala to procure BESS externally through a project developer.	In case of CAPEX deployment, KSEBL would have to take a loan to fund the project, which can be upto 70% of the project cost, depending on Kerala Government VGF provisions.
Project tariff	The per unit cost of electricity supply from the BESS project indicates the financial viability of the project over its lifetime.	Procuring BESS in CAPEX mode would result in a per unit cost ranging from INR 7.5/kWh to 8.1/ kWh* for a 4-hour 1 cycle BESS system excluding VGF and charging costs.	Based on current market trends and tender results, per unit cost of BESS procurement will likely range from INR 5.1/ kWh to INR 5.6/ kWh* for a 2-hour 2 cycle BESS system depending on use case and excluding VGF.	Tariff for 2 cycle systems is typically lower than 1 cycle systems.

- Currently, no bids have been awarded for 1 cycle, 4-hour BESS systems, and thus, market rates are not available.
- The market rates shown for the OPEX model is for 2 cycle, 2-hour BESS systems.

Note: * including charging cost

Qualitative considerations (1/3)

	Description	CAPEX	OPEX	Comments
Value stacking potential	The repayment potential of BESS systems is improved by addressing multiple use cases with a single system, i.e., value stacking.	In case of deployment in CAPEX mode, KSEBL will have control of the system usage, allowing for flexibility to utilize the BESS capacity for other use cases in non-peak hours.	In case of procuring BESS capacity in OPEX mode, KSEBL will benefit from a single use case for which the capacity has been procured. However, other benefits from value stacking will accrue to the developer.	Certain benefits such as distribution transformer CAPEX deferral and improved power quality would be seen in both models in case installation is in Kerala.
Operations and Maintenance (O&M)	Ensuring proper O&M practices over the lifetime of the project is necessary to extract maximum value from the project. The responsibility for O&M will vary depending on model selected.	KSEBL will be responsible for O&M activities including monthly safety checks in case of CAPEX installation. This may be carried out directly by KSEBL staff or be outsourced.	The project developer will be responsible for the O&M activities including monthly safety checks for the BESS project.	In the CAPEX model, KSEBL would also incur O&M expenditure for the project lifetime. In the OPEX model, this cost will be incurred by the developer.

Qualitative considerations (2/3)

	Description	CAPEX	OPEX
Land requirement	Land is an important consideration for an RE project. Although the land requirement for BESS is relatively small compared to solar/wind energy, the distribution of responsibility of land acquisition will affect the final project cost and tariff.	KSEBL will have to identify existing land parcels available with them or procure land for the project themselves. 4-5 acres of land will be required to install 7.4 GWh of storage capacity. If KSBEL does not possess the required land, they may need to consider leasing land based on the project's duration. However, this approach could potentially lead to an increase in the overall storage costs.	4-5 acres of land will be required to install 7.4 GWh of storage capacity. KSEBL may choose to identify land parcels on which developers can install projects. Alternatively, KSEBL may select substations at which the project must be deployed.
Skill development and training requirement	Skilling, awareness creation, and training of on-ground workforce will be necessary to capture BESS benefits and ensure utilization.	KSEBL will need to conduct technical training and skill development to create a workforce equipped to directly operate/manage a BESS project.	KSEBL will only require awareness creation and high-level training on BESS as detailed technical aspects would be in the mandate of the developer.

Qualitative considerations (3/3)

	Description	CAPEX	OPEX	Comments
Technology selection	Selecting the right energy storage technology involves evaluating various factors to meet specific needs. Key considerations include the type of energy storage, the duration of storage required and the intended application. Additionally, economic factors such as cost, efficiency, and lifespan, play crucial roles in the decision-making process.	KSEBL will need to consider the high upfront cost and specialized maintenance needs of PSP, which is better suited for long-term, large-scale applications. Conversely, BESS offers a scalable and modular approach with lower initial costs, though it requires regular monitoring and maintenance. However, BESS is suitable for short storage durations, aligning well with Kerala's peak demand requirements.	KSEBL will need to consider the higher operational cost of BESS, which offers fast response times and is suitable for applications requiring quick deployment. On the other hand, PSP is efficient for large-scale storage and has lower operational costs.	A multi-criteria decision-making approach is often used to balance the factors and select the most suitable technology for specific scenarios, such as addressing the late evening peak demand in Kerala.

Other initiatives for deploying various ESS technologies

Government incentives and policies
- Provide financial incentives such as subsidies and grants to encourage the adoption of ESS technologies.
- Offer tax credits and exemptions for investments in ESS projects.
- Develop risk-sharing mechanisms between the government and private players.

Research and development
- Establish innovation hubs and research centres focused on advancing ESS technologies.
- Foster collaborations between industry and government to drive innovation and commercialization of ESS.

Pilot projects and demonstrations
- Launch pilot programs to demonstrate the feasibility and benefits of various ESS technologies.
- Document and share successful case studies to build confidence and knowledge among stakeholders.
- Scale up successful pilot projects into full-fledged programs.

Grid modernization and Infrastructure development
- Invest in large-scale battery storage for peak shaving, load balancing, and reducing curtailment of renewables.
- Develop policies to integrate behind-the-meter storage with grid operations.
- Use storage to defer costly transmission and distribution (T&D) infrastructure upgrades in congested areas.

Commercial and Industrial sector adoption
- Provide demand charge reductions for industries adopting storage for peak shaving.
- Launch subsidy schemes for residential and commercial consumers installing battery storage with solar panels.

Consumer awareness and Market creation
- Conduct awareness campaigns to educate stakeholders about the benefits of ESS.
- Conduct workshops, conferences, and demonstration projects to educate stakeholders about the benefits of energy storage.
- Develop an online portal for consumers to access information on energy storage options, costs, and financing.

THANK YOU

Annexures

Kerala purchases 40% of its import power from Central Generating Stations

Total Power Purchase at Kerala Periphery (MU)

Source	FY 24
Central Generating Stations at Keralaperiphery (KSEBL end)	10,951
Total IPP, CPP and Co-gen	1,273
Traders	9,020
Power exchanges	3,641
SWAP	844
Deviation Settlement Mechanism	464
Total power purchase	**25,585**

Breakup of Central Generating Stations at Keralaperiphery (MU)

Source	FY 24
Thermal	8,788
Nuclear	2,162
Total	**10,951**

Breakup of total IPP, CPP and Co-gen (MU)

Source	FY 24
Small Hydro	212
Wind	141
Solar	919
Total IPP, CPP and Co-gen	**1,273**

Note: IPPs=Independent Power Producers; CPPs= Captive Power Plants is not considered in total power purchase

Source: Power system statistics report by KSEBL

Kerala's energy demand is projected to grow consistently, with average hourly demand growing by ~750 MW by FY27

Projected hourly demand curve average (MW)

	Historic				Projected		
Particulars	**FY21**	**FY22**	**FY23**	**FY24**	**FY25**	**FY26**	**FY27**
Average	2,807	2,958	3,096	3,473	3,695	3,941	4,223
Difference		152	138	377			
Rolling average difference					222	246	282

Definition and steps

1. The average value is the average of all the hourly demand curve values for a particular financial year.
2. The rolling average difference is estimated by calculating the moving average over the last three financial years.
3. The calculated rolling average difference is added to the hourly demand curve of the previous financial year.

Example: Projecting Kerala FY25 hourly demand curve

The rolling average difference for FY25 is calculated by taking the average of FY22, FY23, and FY24, which is 222 MW. This rolling average difference for FY25, i.e., 222 MW, is added to the hourly demand curve of FY24. It is assumed that Kerala's hourly demand curve profile will remain similar with growth.

Source: KPMG Analysis

Assumptions for EV sales and energy consumption

1

Category-wise CAGR assumed

EV Type	FY25 to FY27
2W	40%
3W	25%
4W	30%
Public service vehicles	15%
Goods and Commercial Vehicles	10%

Each vehicle category will grow at a different rate. Considering the greater demand for EV 2W, it is assumed that the 2W category will grow at a much faster rate than other categories. Similarly, category trends have been considered to estimate category wise growth rate for other categories. These are shown in the table above.

Category-wise daily energy needs

EV Type	Average Daily Run (km)	Energy Consumption (kWh/km)	Daily Individual Energy Need (kWh)
2W	20	0.04	0.80
3W	100	0.08	8.00
4W	40	0.13	5.20
Public service vehicles	120	1.30	156.00
Goods and Commercial Vehicles	200	0.80	160.00

Estimated the energy demand for charging each type of EV, considering the respective energy consumption and daily kilometers travelled.

Source: Vahan Dashboard, Industry interaction, LinkedIn, financial express, EV reporter, e-vehicle Elsevier, WRI, Zing, KPMG Analysis

Kerala will see an additional ~1,100 MW of peak hour load due to EV charging and AC usage by FY27

Annual power demand projection for EV charging (in MW)

Particulars	FY25	FY26	FY27
Annual Energy Demand (MU)	86	110	143
Daily hours of usage	6	6	6
Daily power demand (MW)	234	302	382
Hourly power demand (MW) (during 6 hours of usage)	**39**	**50**	**65**

Annual power demand projection for induction cooktops (in MW)

Particulars	FY25	FY26	FY27
Annual Energy Demand (MU)	81	110	149
Daily hours of usage	3	3	3
Daily power demand (MW)	221	521	929
Hourly power demand (MW) (during 3 hours of usage)	**74**	**100**	**136**

Annual power demand projection for AC (in MW)

Particulars	FY25	FY26	FY27
Annual Energy Demand (MU)	348	400	460
Daily hours of usage	7	7	7
Daily power demand (MW)	1,932	2,222	2,555
Hourly power demand (MW) (during 7 hours of usage)	**276**	**317**	**365**

- EV charging and AC demand will be seen in the late evening/night, coinciding with peak demand hours.

Source: KPMG Analysis

Peak demand is likely to increase by over 1,800 MW by FY27 compared to FY24, with YoY growth of ~530-700 MW over the next three years

Projected peak demand (MW)

Financial Year	Previous year peak demand (MW) (A)	YoY increase in demand (MW) (B)	EV demand addition (MW) (C)	AC demand addition (MW) (D)	Total demand addition (MW) (B+C+D=E)	Estimated peak demand (MW) (A+E)	Explanatory slides
FY25	5,302	222	39	276	537	5,839	58, 60
FY26	5,839	246	50	317	613	6,452	58, 60
FY27	6,452	282	65	365	712	7,164	58, 60

- Considering the impact of increased demand due to EV charging and AC usage, peak demand is expected to rise at a rate of 10.5%, which is significantly higher than the historical rate of 4.6%.

Source: KPMG Analysis

~1.8 GW with 4 hours of storage capacity can meet Kerala's projected peak demand by FY27

Projected potential of storage capacity requirement by FY27

Particulars	FY25	FY26	FY27	Explanatory Slide
YoY increase in peak demand (MW)	222	246	282	58
EV demand addition (MW)	39	50	65	60
AC demand addition (MW)	276	317	365	60
Total value added (MW)	537	613	712	
Total MWh (considering 4 hours duration)	2,148	2,452	2,848	
Storage capacity required by FY27 (GW)			**~ 1.86**	
Storage capacity required by FY27 (GWh)			**~7.45**	

Source: KPMG Analysis