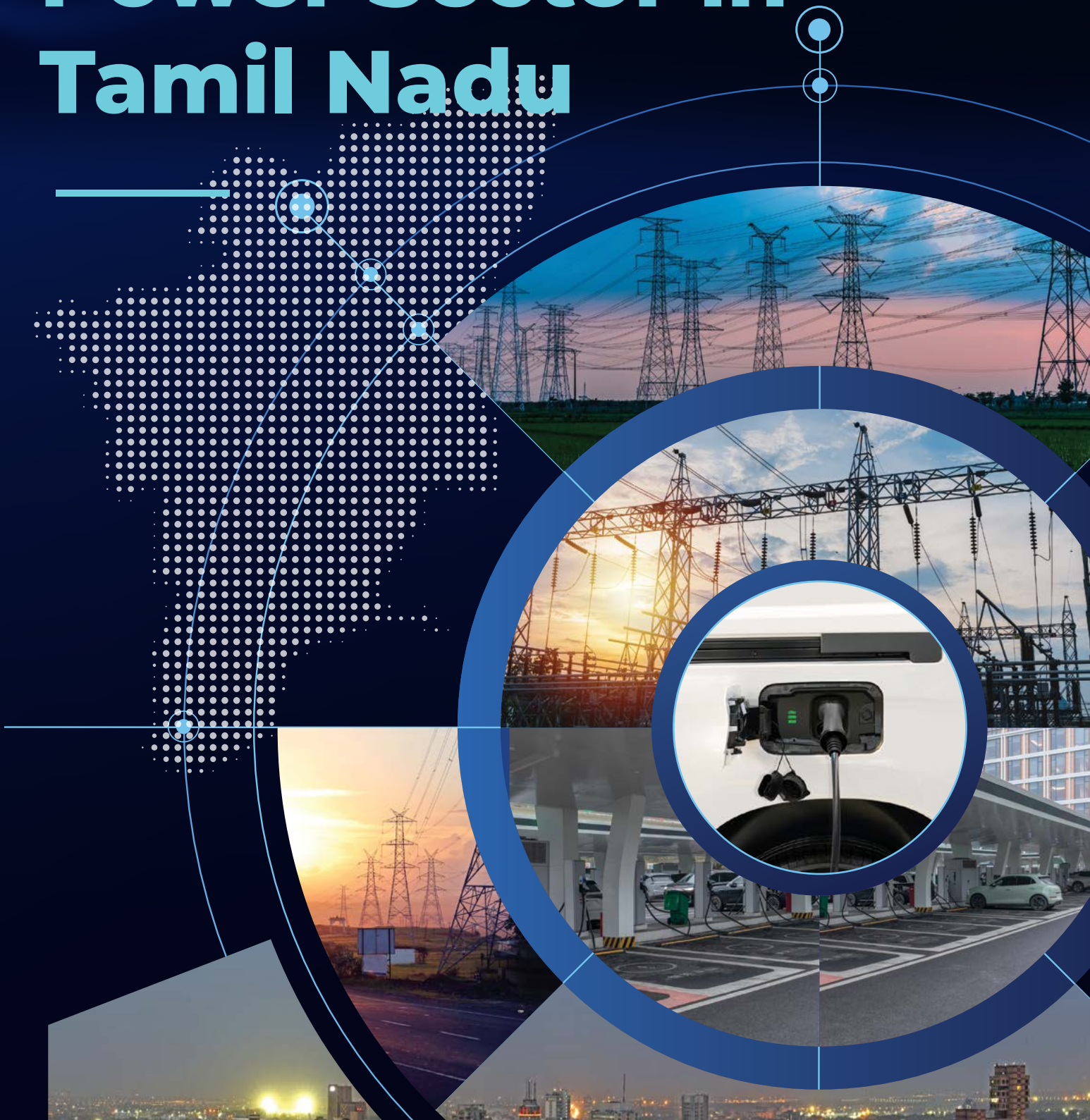


Demand Flexibility for a Resilient Power Sector in Tamil Nadu



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Executive Summary

Tamil Nadu's power system presently faces two converging pressures: rising peak demand and a fast-growing renewable energy (RE) share that is unable to reliably supply power for the hours of highest demand. RE now accounts for nearly 58% of the state's installed capacity, but the mismatch in the timings of abundant solar power generation and the evening demand peak—a classic 'duck curve' pattern—is straining grid balance. The peak demand in the state has grown from 16,386 MW in FY 2019–20 to over 20,000 MW in FY 2025–26 and is projected to reach 35,263 MW by FY 2034–35. Meeting this growth through supply-side capacity additions alone is costly, slow, and can leave assets underutilised for most of the year.

This study makes a case for demand flexibility (DF)—an approach that enables consumers across residential, commercial, and electric vehicle (EV) segments to shift, reduce, or reshape consumption in response to grid conditions—as a complementary, lower-cost lever to capacity addition. At its simplest, DF could mean shifting the use of a water heater to solar-rich hours and at a more advanced level, it could mean buildings, appliances, or EV chargers responding automatically to grid conditions. Drawing on international and Indian experience, the study identifies four recurring design principles for a successful DF programme: understanding consumer behaviour, designing around financial value, automating for scale, and aggregating to unlock participation.

With the aim of developing a long-term DF plan for Tamil Nadu, the study assesses the economic and system value of DF across three key segments: residential, commercial, and EVs. It assesses the potential savings that the state can realise from avoided energy procurement costs, reduced transmission and distribution (T&D) losses, and deferred capacity investments. For each sector, the relevant DF measures are identified and assessed through a cost-benefit analysis (CBA) framework. For residential consumers, eleven measures are evaluated for six appliances that include air conditioners, geysers, and water pumps. For commercial consumers, the analysis covers two DF measures for air-conditioning, while for EVs, it evaluates two measures for managed charging. The measures are assessed for a cohort of 2.5 lakh households, 1.7 lakh commercial buildings, 10,000 EVs, and 500 public EV-charging stations.

The results reveal a sizeable energy-saving opportunity: a DF programme that considers all three sectors as a portfolio can deliver 60–73 MW of flexibility at the morning peak and 207–253 MW at the evening peak, while shifting or saving approximately 156 GWh of electricity annually. This represents an indicative system value of INR 313 crore per year through avoided energy procurement costs, reduced T&D losses, and deferred capacity investments. Importantly, the analysis shows that these measures are financially viable for both participating consumers and utilities, demonstrating that DF can provide meaningful system-wide value.

The report closes with a three-phase roadmap to progressively move demand flexibility from pilot stage towards becoming a core system resource. Phase I (0–3 years) focuses on establishing proof of concept through state-specific pilots that use low-cost automation and retrofittable flexibility devices. In Phase II (3–5 years), the focus is on expanding enrolment among high-potential consumers, strengthening tariff signals, and developing an aggregator ecosystem to bring smaller and distributed loads into the programme. Finally, Phase III (beyond 5 years) heads towards formally recognising verified demand flexibility in resource adequacy and long-term power system planning, establishing it as a market resource that can be procured alongside conventional supply-side resources.

Thus, the roadmap aims to establish demand flexibility as a system resource alongside conventional capacity, equipping Tamil Nadu with another tool for managing the rising peaks and growing RE penetration. Acting promptly on the roadmap would allow the state to strengthen its power sector demand management at a fraction of the cost of adding new capacity.

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Abbreviations

Abbreviated form	Expanded form
AC	Air conditioner
CAGR	Compound annual growth rate
CEA	Central Electricity Authority
DER	Distributed energy resource
DF	Demand flexibility
DSM	Demand-side management
EV	Electric vehicle
E2W / E3W / E4W	Electric two-wheeler / three-wheeler / four-wheeler
FY	Financial year
GW	Gigawatt
GWh	Gigawatt hour
HVAC	Heating, ventilation, and air conditioning
IoT	Internet of Things
kW / kWh	Kilowatt / kilowatt hour
LRI	Life-cycle revenue impact
LT	Low tension
MNRE	Ministry of New and Renewable Energy
MSME	Micro, small, and medium enterprise
MU	Million units
MW	Megawatt
M&V	Measurement and verification
NESO	National Energy System Operator (United Kingdom)
NPV	Net present value
Ofgem	Office of Gas and Electricity Markets (Great Britain)
P2P	Peer to peer
RE	Renewable energy
RES	Renewable energy sources
RIM	Rate-payer impact measure
T&D	Transmission and distribution
TNERC	Tamil Nadu Electricity Regulatory Commission
TNPDCL	Tamil Nadu Power Distribution Corporation Limited
ToD	Time of day



1. The Study: Context and Objectives

Tamil Nadu has been a frontrunner in renewable energy (RE) deployment, with solar and wind energy now forming nearly 58% of its installed capacity mix. At the same time, the state is grappling with a steadily rising electricity demand, with peak demand hitting record levels year after year. Together, these two trends pose a formidable challenge for power sector planners, the core question being: how to make the best use of intermittent RE sources—whose availability does not always align with the period of highest consumer demand—to tackle the surging overall electricity demand as well as peak-demand instances. The issue of mismatch between generation and consumption cannot be addressed by capacity additions. It calls for actively managing demand itself—shifting and shaping consumption to match RE generation. This is the premise of demand flexibility (DF) and the subject of our study.

The objective of this study is to identify the DF potential in the state of Tamil Nadu. It does so by estimating the economic and system value—avoided energy costs, avoided transmission and distribution (T&D) losses, and deferred capacity investment—of demand flexibility across Tamil Nadu's residential, commercial, and electric vehicle (EV) segments. The assessment follows a bottom-up methodology: for each segment, a realistic consumer cohort is defined, loads within that cohort are sorted by their flexibility, and appropriate DF measures are applied to convert connected load into firm relief at the system peak. This relief is then valued in terms of avoided capacity and energy saved or shifted, with every measure screened against three standard cost-effectiveness tests.

The report is organised into four main parts. The following section (Section 2) describes how the demand and generation trends place Tamil Nadu's grid under stress, while Section 3 presents demand flexibility as the opportunity, drawing on international and Indian experience to establish the design principles a long-term programme must follow. Moving on, Section 4 quantifies the demand flexibility potential available across the residential, commercial, and electric vehicle (EV) segments in Tamil Nadu, and assesses the value this potential can return to the power system. Finally, Section 5 translates these findings into a phased roadmap for Tamil Nadu to act on.

2. The Gap: State Power System Under Stress

2.1. Tamil Nadu's power sector landscape

Tamil Nadu has shown impressive progress in integrating its RE resources into the grid. As of June 2026, the state's installed capacity stood at 47,978 MW, with the share of RE capacity steadily increasing in the energy mix over the past several years.

Table 1. Source-wise installed capacity in Tamil Nadu in FY 2025- 26

Source	Capacity (MW)	Share of total
Coal	13705.49	28.6%
Lignite	1,916.57	4.0%
Gas	844.58	1.8%
Diesel	211.70	0.4%
Nuclear	1,448.00	3.0%
Hydro	2,203.20	4.6%
Renewable energy sources* (MNRE)	27648.43	57.6%
Total	47,977.97	100%

Installed Capacity as on 31 June 2026 (CEA, 2026)

**Renewable energy sources include small hydro projects, biomass power, urban and industrial waste power, and solar and wind energy.*

Renewables, including solar and wind, make up nearly 58% of the state's installed capacity, clearly indicating the transition of a coal-dominated generation mix towards an RE-dominated one. Coal continues to provide balancing and baseload support alongside nuclear, hydro, and gas.

2.2. Peak-demand trends

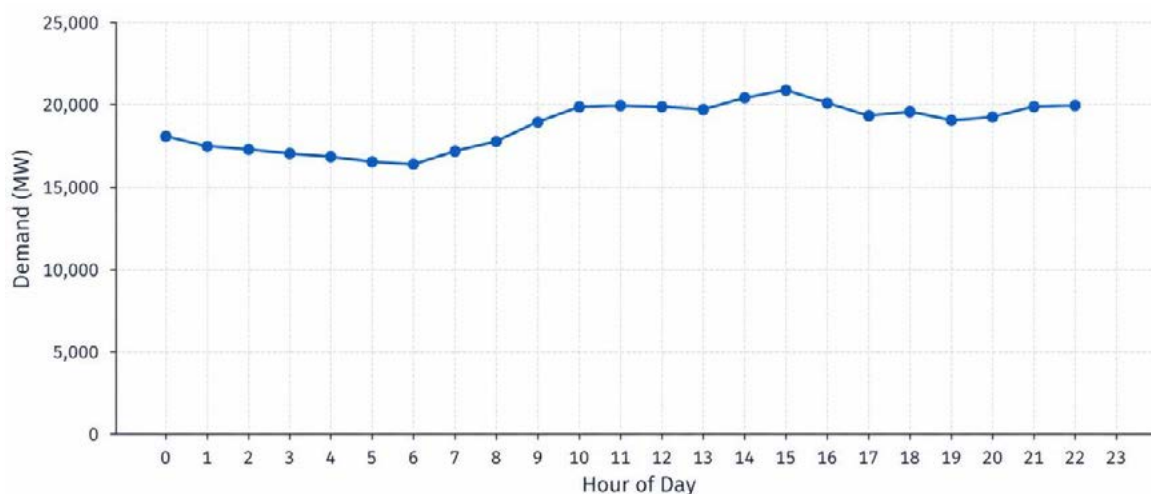
The state's peak electricity demand has shown a steady upward trend, increasing from 16,386 MW in FY 2019-20 to 20,830 MW in FY 2024-25, at a compound annual growth rate (CAGR) of approximately 4.9%. Although the recorded peak demand in FY 2025-26 (20,211 MW) is marginally lower than that in FY 2024-25, the overall trajectory indicates a sustained growth that is driven by increasing electrification, urbanisation, industrial activity, and rising residential consumption. The year-on-year (YoY) peak-demand trend and the typical hourly state demand curve are presented in Table 2 and Figure 1, respectively.

Table 2. Year-on-year peak demand in Tamil Nadu

Fiscal year	Peak demand (MW)
FY 2019-20	16,386
FY 2020-21	16,481
FY 2021-22	17,196
FY 2022-23	18,053
FY 2023-24	19,387
FY 2024-25	20,830
FY 2025-26	20,211

Source: Data Collected from TNPDC

Figure 1. Typical hourly load-curve for Tamil Nadu

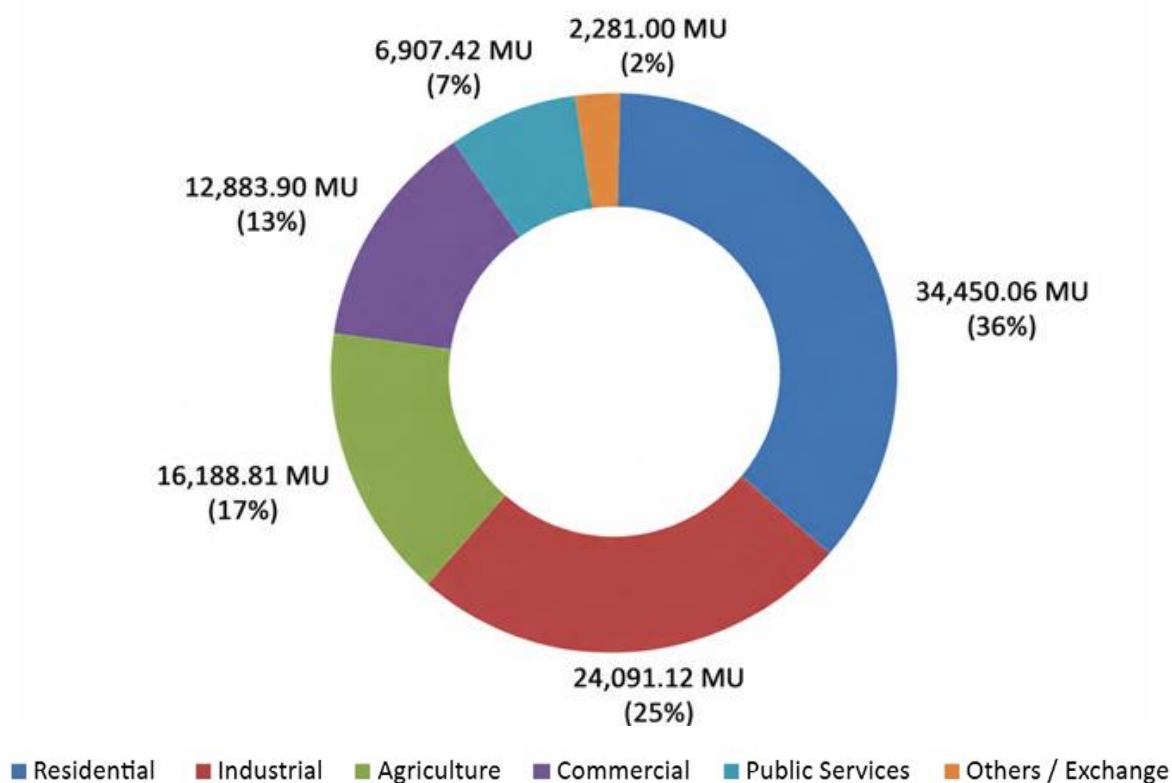


Source: Data collected from TNPDC

2.3. Consumption across consumer categories

In FY 2024-25, the state's total electricity consumption stood at 96,802 million units (MU) (Tamil Nadu Electricity Regulatory Commission, 2026a), with the residential category accounting for the largest share of 34,450 MU (36%). The industrial category was the second-largest consumer with 24,091 MU (25%), followed by agriculture with 16,189 MU (17%), and the commercial category with 12,884 MU (13%). Public services consumed 6,907 MU (7%), while other categories accounted for 2,281 MU (2%). Overall, the category-wise consumption indicates the prominence of the residential and industrial categories, which together account for nearly two-thirds of the state's electricity demand, making them the key focus areas for demand-side management, energy efficiency measures, and integration of distributed energy resources (DERs).

Figure 2. Category-wise energy consumption in Tamil Nadu in FY 2024- 25 (MU)



Source: (Tamil Nadu Electricity Regulatory Commission, 2026b)

2.4. Supply-side additions alone are insufficient

As Tamil Nadu's power system absorbs larger shares of solar- and wind- based generation, the conventional planning paradigm—building supply to meet a relatively predictable demand curve—is becoming inadequate. The rising peak demand and the growing RE share challenge the grid from two directions (the supply and demand sides) at once. The traditional approach of relying on capacity additions for thermal and hydro plants or costly power purchases from energy markets may have been able to bridge the demand-supply gap in the past but it would not be effective for the current scenario.

There is, however, another lever available to system planners, which is currently underutilised: shaping demand itself to match what the grid can already provide. In the section that follows, demand flexibility is presented as a critical measure to address the challenges faced by the state.



3. The Opportunity: Making Demand an Energy Resource

3.1. What is demand flexibility

Demand flexibility refers to the ability of electricity consumers—households, industries, commercial establishments, and increasingly, electric vehicles (EVs)—to shift, reduce, or reshape their consumption in response to grid conditions, price signals, or RE availability (Ma et al., 2026). Instead of treating demand as fixed and building system capacity around it, a flexible grid considers electricity consumption as a resource that can be actively managed—shifting demand towards hours when RE generation is abundant and reducing demand during periods of system peak.

A simple example of demand flexibility in the case of residential consumers would be using appliances such as water heaters and washing machines during solar hours. For commercial consumers, it could mean pre-cooling stores and office spaces during off-peak hours. Large facilities can shift heavy-machinery operations to periods of abundant solar and wind power generation. These measures can produce substantial impact. Reducing peak demand can defer the need to build new power plants, reduce transmission and distribution (T&D) losses, and—most importantly—reduce high power purchase costs.

Managing demand instead of expanding supply is a well-established approach. Demand-side management and energy conservation programmes have long been a part of India's distribution planning. The Energy Conservation Act, 2001 was specifically enacted to promote energy efficiency programmes, and created the Bureau of Energy Efficiency to enforce consumption-side programmes to effectively reduce energy demand (Sahoo et al., 2016). Programmes focussing on energy-efficient appliances, load shedding, and time-of-use tariffs share the objective of reducing or shifting demand to alleviate stress on the grid.

Demand flexibility builds on demand-side management measures but takes it further from relatively static or pre-defined interventions to more proactive, continuous, and dynamic measures (Chen et al., 2018). Rather than simply reducing overall consumption, demand flexibility enables loads to respond to real-time grid conditions, system requirements, and price signals. For this reason, demand flexibility relies considerably on smart technologies and digital infrastructures (Hussain et al., 2023).



Demand flexibility defined

According to Maharashtra Electricity Regulatory Commission (2024), demand flexibility *'means the capacity of demand-side loads that can vary their consumption patterns hourly or on another timescale to help integrate higher amounts of renewable energy resulting in making electricity more affordable to consumers with the co-benefits of reducing or deferring system costs or an end-use consumption that can increase or decrease as a demand response measure.'*

3.2. The case for demand flexibility in Tamil Nadu

For Tamil Nadu, the case for demand flexibility rests on three converging factors:

- i. The state's solar-heavy generation profile creates a midday surplus that declines sharply by early evening, precisely when demand from homes and businesses tends to rise, a pattern commonly described as the 'duck curve' problem;
- ii. With peak demand having grown substantially over the past 6 years and expected to reach 27,090 MW in FY 2029-30 and 35,263 MW by FY 2034-35 as per the resource adequacy plans of the Central Electricity Authority (CEA), meeting peak load purely through new capacity additions is challenging, both financially and in terms of underutilised assets that sit idle for most of the day (CEA, 2026);
- iii. Tamil Nadu's consumer base—dominated by residential and industrial consumption that together account for 61% of the state's total consumption —represents a largely untapped pool of flexible load that, if engaged even modestly, could relieve the stress on the grid without fresh investment in generation.

Unlike capacity addition, demand flexibility does not require new power plants or enhanced transmission infrastructure to deliver value. It works through relatively simple upgrades, such as smart tariffs, storage, automation, and consumer participation, to make the existing grid work smarter. As our study reveals, this shift is no longer optional for a state with a high RE share, such as Tamil Nadu. It is a structural need for maintaining grid reliability while continuing with decarbonisation.

3.3. Understanding flexibility behaviours

The findings of the literature review conducted for this study (Agbonaye et al., 2021; Chen et al., 2018; Hussain et al., 2023) indicate that demand flexibility can be implemented through a range of mechanisms that have varying levels of consumer engagement, financial incentives, and technological automation. These are categorised in the table below. Table 3.



Table 3. Understanding the different types of demand flexibility measures

Type of demand flexibility	How it works	Typical participants	Primary motivation	System/ market enablers
Behavioural flexibility	Consumers voluntarily shift or reduce electricity use; for example, shifting appliance use to off-peak or solar-power-generation hours	Residential consumers	Lower bills, environmental benefits, or personal preferences	Peak-period signals via SMS/WhatsApp; consumer information and awareness campaigns; energy-monitoring tools; time-of-day (ToD) tariffs
Price- and incentive-based flexibility	Consumers respond to electricity prices, tariffs, or financial incentives by shifting or reducing consumption	Residential consumers, commercial buildings, Micro, Small, and Medium Enterprises (MSMEs)	Financial savings and incentives	Dynamic/ToD tariffs; smart meters; demand-response programmes; financial incentives
Technology-enabled/ automated flexibility	Smart appliances, energy-management systems, batteries, rooftop solar systems, EVs, etc. automatically adjust consumption or generation in response to system or market signals	Residential, commercial, industrial and public-sector consumers	Bill savings; participation in energy/flexibility markets; revenue from providing grid services; decarbonisation	Smart meters and Internet of things (IoT) infrastructure; automated control platforms; interoperable standards; flexibility markets; subsidies or other technology incentives

3.4. Planning for a long-term demand flexibility programme

A review of the guiding principles of a successful demand flexibility programme and international and Indian experiences point to four recurring themes for implementing demand flexibility. These are: understanding consumer behaviour, designing around financial value, using automation to achieve scale, and using aggregation to unlock participation. These tenets appear consistently across the literature reviewed as well as in real-world programmes. They are discussed below alongside examples of how they have been applied.

Principle 1: An understanding of consumer behaviour

Consumer participation is the foundation of demand flexibility. Scaling up demand-side measures requires consumers to understand their role in reducing energy consumption and the long-term benefits of their participation (Sustainable Energy Authority of Ireland, 2025). Before scaling up a demand flexibility programme, the implementing agencies must understand the behaviour of electricity consumers through surveys, invest in educating the public on their energy use, and spread awareness regarding the benefits of participation (Brent et al., 2017).

Examples

The Office of Gas and Electricity Markets (Ofgem), the energy regulator for Great Britain, conducted a survey in 2025 to understand the energy attitudes and experiences of residential consumers to implement flexibility products (The Office of Gas and Electricity Markets, 2026). The survey was designed to understand consumer perceptions of flexibility products and their willingness to change their usage of EV chargers, washing machines, and heat pumps. In addition, the National Energy System Operator (NESO), the United Kingdom's electricity system operator, issued communication principles for tariffs stating that information should be available in simple language and should be widely accessible and multilingual (National Energy System Operator, 2026).

Similarly, the Sustainable Energy Authority of Ireland recommended that the first stage of implementing demand flexibility must involve education about the benefits of reducing peak demand, including the environmental impact (Sustainable Energy Authority of Ireland, 2025).

In October 2018, BSES Rajdhani Power Limited (BRPL) launched a 'Behavioural Energy Efficiency Programme' in Delhi where approximately 2 lakh consumers were provided bi-monthly reports with information on their energy use benchmarked against average energy use (Sachar et al., 2019). Using a simple interface, the reports offered recommendations on reducing energy use. The programme led to an estimated saving of 1-3% on household electricity costs (BSES Rajdhani Power Limited, 2020).

Principle 2: Financial-value-based design

One of the major benefits of demand flexibility is financial savings, which happens mainly through avoided power procurement costs, avoided T&D losses, and deferred capacity charges (International Energy Agency, 2025). However, to realise these benefits, the financial value of the flexibility must be clearly defined and also be measurable. Incentives and payments should, therefore, be linked to the actual reduction, shift, or curtailment in electricity consumption. Robust measurement and verification (M&V) mechanisms are also essential to establish the amount of flexibility delivered and ensure that participants are compensated accurately and fairly (Goldberg & Agnew, 2013).

Examples

In 2022, the California Public Utilities Commission published a white paper titled *Advanced Strategies for Demand Flexibility Management and Customer DER Compensation* that outlined strategies to scale up demand flexibility through dynamic pricing, improved customer compensation, and greater integration of DERs (California Public Utilities Commission, 2022). Of its six guiding objectives, one provides that policy should ensure full recovery of costs associated with implementing demand flexibility measures, in line with cost-causation principles and the avoidance of cost shifts.

In India, the first demand flexibility regulations were issued by the Maharashtra Electricity Regulatory Commission in 2024 and subsequently by other states. The regulations mandate the use of three cost-effectiveness tests, requiring the measures to meet all these tests before initiating implementation (Maharashtra Electricity Regulatory Commission, 2024):

- 1) Total resource cost, where the programme must show a positive net present value (NPV) of benefits over costs;
- 2) Rate-payer impact measure (RIM), which confirms that implementation and costs will not affect tariffs; and
- 3) Life-cycle revenue impact (LRI), under which measures that do not pass the RIM test should not affect the tariff by more than INR 0.005/kWh or more than 0.05% of the existing tariff.

Principle 3: Automation enables scale

One key feature that differentiates demand flexibility from other demand-side measures is automation. Demand flexibility measures must be able to respond automatically to system conditions, particularly tariffs variations and peak demand (Nubbe et al., 2020). For a technological option to work, it should include two-way communication, ability to respond to the grid, and ability to verify energy savings. While smart meter penetration continues to grow, retrofit options such as smart switches and plugs can support demand flexibility in the interim.

Examples

In 2024, 1,000 residential consumers of Tata Power were provided smart switches costing approximately INR 5,000 each, which could automatically turn off the supply to connected devices and monitor power consumption. Almost 80% of the smart switches were connected to air-conditioner (AC) units, but were also compatible with refrigerators, geysers, ovens, washing machines, and electric-car chargers. The initiative led to a reduction of around 2–3% in carbon-dioxide (CO₂) emission on average and a cost savings of 2.3% on average for the households. Most importantly, energy demand reduced by up to 15% on average during the late afternoon and evening peak-demand hours (Kane et al., 2024).

In South Africa, a local municipality launched a pilot project between August 2022 to August 2023, under which smart devices were fitted to water heaters in 100 households (later expanded to 500 households). The device, called the HotBot, is an artificial-intelligence-powered geyser-controller that automatically adapts to load-shedding schedules. The results were significant: up to 80% reduction in peak energy consumption, up to 60% reduction in maximum demand, and noticeable household savings (Cheung, 2023).

Principle 4: Aggregation unlocks participation

Most residential and commercial consumers are too small to individually participate in flexibility schemes. Aggregation can overcome this constraint by combining a large number of small, distributed loads into a resource capable of providing measurable flexibility service. As the adoption of DERs such as rooftop solar systems, Battery and Energy Storage Systems (BESS), and EVs increases, aggregation can enable them to participate in electricity and flexibility markets. Aggregators would therefore play an increasingly important role in integrating small-scale resources into power markets (International Energy Agency, 2022).

Examples

In 2023, the Australia Energy Market Operator (AEMO) launched Project EDGE (Energy Demand and Generation Exchange), a multi-year project to demonstrate how DERs can be tapped as a flexible system resource in Australia. Initiated after the publication of a detailed report, the project views aggregators, i.e., actors that manage the DERs from many customers, as critical stakeholders for flexible and scaled-up DER integration. The report discussed the need to simplify the aggregator experience and identify ways for aggregators to access multiple revenue streams (Australia Energy Market Operator, 2023).

In the United Kingdom, approximately 3,00,000 devices, including EVs and BESS were combined into a virtual power plant, representing more than 2 GW of flexible capacity across Great Britain alone. Consumers were offered tariffs up to 60% lower in exchange for allowing the aggregator to manage their vehicle charging. The aggregator could then shift EV charging away from peak hours and trade this flexible capacity with network operators, generating value from the flexibility provided by consumers. Between 2022 and 2029, the aggregator has been awarded an average of 226 MW of capacity obligations per year. The aggregator had the ability to control the vehicle charging system and shift its use away from high-cost periods, using real-time wholesale prices as a key input (Metcalf et al., 2026).



4. The Evidence: Quantifying the Demand Flexibility Potential in Tamil Nadu

The study assesses the economic and system value of demand flexibility across the residential, commercial, and electric vehicle (EV) segments in Tamil Nadu. The assessment considers three sources of value: avoided energy procurement costs, avoided transmission and distribution (T&D) losses, and deferred capacity investment.

These segments were chosen because each holds a notably different kind of flexibility potential, and each is accessed through a different means, like a smart plug in a household, a contract with a building operator, a controller on a vehicle charger. The assessment therefore considers both, the scale of flexibility available and the practical mechanisms through which it can be delivered.

4.1. Methodology

The study takes a bottom-up approach to analyse the cost and benefits, starting from a single household, building, or vehicle and estimating how much peak demand and energy each measure reduces. It scales that up using assumed programme participation and then values the resulting savings. The DF measures were identified through a literature review of successful programmes and the cost-benefit analysis (CBA) model was developed with inputs from stakeholders.

4.1.1. Data collection

The assessment considers four sets of data, used along with literature review to identify appliance characteristics. These are:

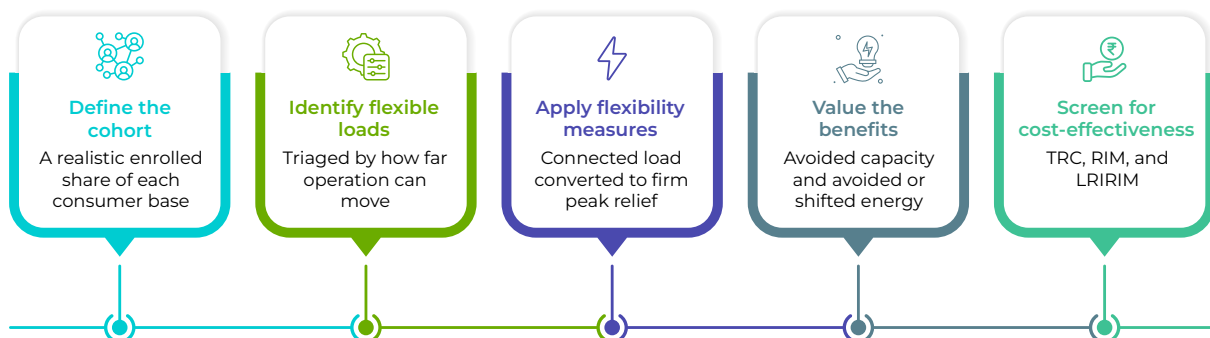
- i. **State demand data for 5 years:** Hour-by-hour demand for Tamil Nadu across the last 5 FYs, used to establish the shape of the load curve, identify when the system actually peaks, and project demand forward to the target year.
- ii. **T&D loss data:** Used to aggregate the savings measured at a consumer's meter to the energy actually avoided at the generation bus.
- iii. **Generation and capacity data:** Plant-level details used to establish which generation is displaced at the peak and what a deferred MW of capacity is worth.
- iv. **Tariffs and power procurement cost data:** Retail tariffs, consumers by category, and procurement costs from TNERC tariff orders, used to value avoided energy and the revenue the utility forgoes.

4.1.2. Stakeholder consultations

Consultations were held with the planning, demand-side management, smart grid and IT teams at TNPDC, with TNERC, and with the State Load Despatch Centre (SLDC). These discussions were utilised for confirming the declared peak windows, to test whether the appliance-usage patterns assumed were reasonable for Tamil Nadu, and to sense-check the programme cost and incentive assumptions against what a utility could realistically administer.

4.1.3. Development of a CBA framework

The analysis for developing a CBA framework follows five steps. First, a representative consumer cohort is defined for each segment considering the relevant consumer base and realistic participation assumptions. Second, loads within each cohort are assessed according to the extent to which their operation can be shifted or reduced without materially affecting the service provided. Third, flexibility measures are applied to the loads that are technically and operationally capable of responding and translating the connected load into reliable peak-demand reduction. Fourth, the resulting flexibility is valued in terms of avoided capacity investment, avoided energy procurement, and avoided T&D losses. Finally, each measure is assessed against three cost-effectiveness tests (Total Resource Cost [TRC], Rate-Payer Impact Measure [RIM], and Life-Cycle Revenue Impact [LRIRIM]) to determine whether the estimated benefits justify the associated implementation and enabling costs.



For every measure, the assessment establishes three things. First, how much demand is actually reduced during the peak hour; second, how many units of energy are saved or shifted out of peak hours over a year; and third, what benefits this brings to the power system (the avoided power purchase cost, the network losses avoided along with it, and the new generation capacity that can be deferred).

Not every enrolled participant or appliance is switched on during the hour that matters, so coincidence factors are applied throughout to convert connected appliance load into firm relief at the system peak. All results are presented as ranges, reflecting a $\pm 10\%$ band on the assumptions that convert connected load into firm relief at the peak. The appliance-wise figures and the underlying assumptions on ownership, coincidence factors, and unit costs are presented in the Appendix. Every measure is evaluated against the standard cost-effectiveness tests applied to demand-side programmes: the participant test, which asks whether an enrolled consumer is better off; after being enrolled; the utility cost test, which asks whether avoided supply costs exceed what the utility spends to procure the reduction; and the rate impact test, which asks whether consumers who do not participate become worse off. The participant and utility tests are assessed on the net present value and the cost-benefit ratio, respectively, while the rate impact test measures the effect on tariffs in rupees per unit against a regulatory limit of INR 0.005/kWh.

4.1.4. Assumptions

The DF potential for each segment is assessed for an assumed number of participants, sized as a share of the consumer base that a demand flexibility programme could realistically enrol. Those shares differ widely because the bases themselves differ in size and in how easily they can be reached. The residential category is, by far, the largest category with 2.42 crore consumers, so even a modest share means a substantial participation in a DF programme in absolute terms. However, since each participant has to sign up individually, people might find it difficult to enrol, which may bring down the total enrolment from the

segment. Though commercial buildings and electric vehicles are far fewer, they can be reached through a smaller number of operators and dealerships, so a higher proportion of each can be enrolled.

Table 4. Programme participation assumptions (by segment)

Segment	Addressable consumer base	Participation assumed	Enrolment assessed
Residential	2.42 crore residential consumers	~1%	2,50,000 households
Commercial	38 lakh commercial consumers	~5%	1,70,000 buildings
Electric vehicles	5 lakh electric vehicles	~2%	10,000 vehicles
Public charging infrastructure	1781 public charging stations	~30%	500 charging stations

These assumed enrolment levels represent how much participation an active DF programme could realistically bring in; they are not projections of a future consumer base. Because the results scale up almost linearly with enrolment, the figures presented here should be read as a conservative lower bound rather than an upper limit.

4.2. Sector-Wise Cost-Benefit Analysis

The results for the consumer categories studied are presented in the following sub-sections. For each category, the flexible loads are identified, the DF measures are described, and the resulting capacity and energy contributions are reported.

4.2.1. Residential

Overview

The residential segment is the single largest consumer group in Tamil Nadu by consumer count. Of the 3.3 crore registered electricity consumers (approximately) in the state, around 2.42 crore are residential connections. Residential demand represents a significant share of total consumption but is distributed across a very large number of small consumers. The collective response of millions of households during peak periods, therefore, has a significant impact on the overall load curve and creates substantial potential for demand flexibility.

Table 5. The residential segment: scale and scope

~2.42 cr Residential consumers in Tamil Nadu	2,50,000 Households assessed	6–10 a.m. 6–10 p.m. Peak periods observed	9 a.m.–5 p.m. Solar hours
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A large share of the state's recent demand growth has happened in the residential segment, driven by cooling needs. The Tamil Nadu Electricity Regulatory Commission (TNERC) treats 6:00–10:00 a.m. as the morning peak period and 6:00–10:00 p.m. as the evening peak period, with 10:00 p.m.–5:00 a.m. treated as off-peak hours. The measures assessed here work by moving the load out of the two peak-period windows and into the middle of the day, when solar generation is high, or into the off-peak hours.

Table 6. Consumption trend of the residential load (based on secondary research)

Window	Dominant residential loads
Morning 6–10 a.m.	Water heaters (geysers), water pumps, washing machines, kitchen appliances, and refrigerators
Midday 9 p.m.–5 p.m.	Low residential occupancy; abundant and low-cost solar generation. This is the preferred destination window for any shiftable load.
Evening 6–10 p.m.	ACs and fans, lighting, kitchen appliances, dishwashers, a second geyser cycle, and continuous refrigeration.

Note: Appliance-usage patterns and the allocation of loads to peak windows are drawn from published sources and standard engineering references, validated through consultations with TNPDC, TNERC and the State Load Despatch Centre. They are not based on a primary consumer survey or metered appliance-level data.

Which loads are flexible

Not all residential consumption can be moved. For the purpose of this assessment, appliances are grouped by how easily their operation can be rescheduled or modified without affecting the needs of the consumer.

- **Easy to shift:** water heaters, washing machines, dishwashers, and water pumps. These deliver a stored or batch service, like hot water, clean clothes, a filled tank, so when the appliance runs is largely invisible to the user as long as the output is ready in time.
- **Partly flexible:** air conditioners (ACs). As a building holds its temperature for a while, it can be cooled using ACs ahead of the peak or ACs can be run with short setpoint adjustments, with little perceptible loss of comfort.
- **Largely inflexible:** lighting, fans, televisions, mobile and small-device charging, and refrigerators. These are used whenever people are at home and cannot be moved, so they are left out of the measures assessed here.

For the measures assessed below, only the first two groups have been considered. The measures rely on controls, timers, setpoint discipline, and scheduling, rather than on asking households to consume less of the service they want.

Measures assessed

Six appliance categories account for the bulk of the flexible residential load. For each, the specific demand-side measures analysed are presented in Table 7.

Table 7. Appliance-wise residential DF measures

Air Conditioner Evening peak		Water Heater Morning peak	
Measure	What it does	Measure	What it does
Setpoint Reduction	Holds the thermostat at 24–26 °C, instead of lower settings, reducing compressor loading through the evening.	Timer	Schedules the heating cycle to finish before the morning peak begins, moving the load into the preceding off-peak hours.
Pre-Cooling	Cools the space ahead of the evening peak and relies on the building's thermal mass once the peak begins.	Setpoint Reduction	Lowens the tank thermostat to about 50–55 °C, reducing both heating energy and standing losses.

Washing Machine Morning peak		Water Pump Morning peak	
Measure	What it does	Measure	What it does
Delay Start	Uses the built-in delay timer to run the wash cycle during solar hours rather than during the morning peak.	Solar Scheduling	Fills the overhead tank during solar hours instead of the early-morning peak.
		Variable Frequency Drives	Adds a variable frequency drive so that the motor runs at part load rather than repeatedly starting at full power.

Dishwasher Evening peak		Refrigerator Continuous	
Measure	What it does	Measure	What it does
Delay Start	Defers the wash cycle from the evening peak to late night or the next solar window.	Defrost	Moves the automatic defrost cycle out of peak hours to off-peak or solar hours.
Eco Mode	Selects the low-temperature eco programme, cutting the water-heating share of the cycle.	Setpoint Adjustment	Raises the cabinet setpoint modestly within safe food-storage limits, cutting compressor runtime.

Results

For the 2.5 lakh household cohort, the assessment indicates the following results:

Table 8. Indicative results (for 2.5 lakh residential consumers)

~113–138 MW Capacity saved during peak hours	~116–142 GWh Energy saved or shifted out of peak hours	~INR 162–198 crore Indicative gross annual system-level benefit
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Since the state has two peak-demand windows and household appliances operate on both sides of the day, the segment's contribution is split almost evenly between them.

Table 9. Residential contribution by peak window

Peak window	Measures active during this time	Load reduction (MW)
Morning window 6–10 a.m.	Water-heater timer, washing-machine delayed start, pump scheduling	66.4
Evening window 6–10 p.m.	Air-conditioner pre-cooling and setpoint reduction, dishwasher delayed start	68.1

This balance is what makes the residential sector distinctive. Air conditioning drives the evening contribution, while water heating, laundry, and pumping drive the morning. The two halves cannot be added together, because the system peak occurs only once in the day.

Which Measures to Prioritise

Based on ease of implementation, cost, and energy savings, the following three measures stand out as the most beneficial and can be the ones to begin with:



Water heater: Timer control

This is the biggest contributor in the morning and the most cost-effective measure assessed. A simple timer or smart plug pays for itself several times over in the first year. Hot water is stored, so the household does not notice when the heating actually happens, and geysers are common in urban and semi-urban homes.



Washing machine: Delay start

Washing is a job that can wait, and most machines already have a delay timer. Moving the wash out of the morning peak and into the 9 AM–5 PM solar window costs almost nothing and directly supports the aim of using more of the state's midday solar power.



Air conditioner: Pre-cooling

Cooling a building before 6 p.m. can maintain a comfortable temperature inside through the retained coolness, while shifting a large block of demand to solar hours. As this measure works on the fastest-growing part of household demand, it would become more valuable every summer as an increasing number of homes buy air conditioners.

4.2.2. Commercial

Overview

The commercial category is among the most concentrated load groups in Tamil Nadu's power system, with around 38 lakh registered consumers. Air conditioning dominates demand in offices, retail chains, malls, hotels, hospitals, and institutional buildings, where it is centrally controlled and a single instruction can move a meaningful block of load.

Table 10. Commercial segment: scale and scope

~38 lakh	Buildings assessed	6–10 p.m.	60 × 2 hrs
Commercial consumers in Tamil Nadu	1,70,000	Hours when commercial demand and the system peak coincide	DF events per year (as assessed)

Commercial demand differs from residential demand in two respects, which shape how its flexibility is captured. First, heating, ventilation, and air conditioning (HVAC) loads account for the largest share of a commercial building's connected load and for almost all of its peak-hour variability. Second, typically these buildings are already fitted with centralised HVAC plants, building-management systems, and have facilities staff, so a reduction can be dispatched on instruction rather than depending on the building occupants. Commercial demand flexibility is therefore event-based and contractual. On a called event, the utility instructs enrolled buildings to reduce load for a defined period.

Table 11. Consumption trend in the commercial segment

Window	Dominant loads
Morning 6–10 a.m.	Building start-up (includes HVAC, lifts, lighting, and signage as premises open). A small but rising addition to the morning peak.
Midday 9 a.m.–5 p.m.	Full occupancy; air conditioning at its maximum. Coincident with the solar window and therefore well matched to generation; not a priority for shifting.
Evening 6–10 p.m.	Retail outlets, malls, restaurants, hotels, and hospitals remain occupied and cooled while offices wind down for the day.

Note: The trend is based on published sources and engineering references, and validated through stakeholder consultation. They are not derived from a primary consumer survey.

Which loads are flexible

Commercial premises carry a mix of loads that differ sharply in how far they can be curtailed without an adverse effect on running the business.

- **Easy to shift:** *centrally controlled ACs.* A large building holds its temperature for a while, so cooling can be reduced or delayed for a limited period without the people inside feeling much difference and the change can be made remotely across many buildings at once.
- **Partly flexible:** *non-essential lighting, escalators, and façade and signage illumination.* These can be dimmed or switched off during an event, but the savings are small on their own and they are not assessed here.
- **Largely inflexible:** *refrigeration in food retail, IT and server rooms, lifts, and safety and emergency systems.* Since these are either continuous or are needed for safety, they are excluded from the assessment.

Measures assessed

As is evident, air conditioning is the largest single load in commercial buildings and the only one that can be reduced at short notice without affecting the business. Lighting, lifts, refrigeration and IT loads are either too small to matter or essential for safety. Therefore, measures in the commercial segment are proposed and analysed for ACs only.

Two measures are proposed, the first one being a setpoint raise. When an event is called, the thermostat is turned up by a degree and a half, so that the AC draws less power. The energy is genuinely 'saved' as it is never used at all.

The second is pre-cooling. The building is cooled slightly below its usual setting in the hours before the event, so the compressor can coast through the event window. Here the energy is not saved but moved to the earlier part of the day. Though both measures can act on the same AC unit over the same event window, they are alternatives rather than additions: a building either raises its AC setpoint during the event or cools before the event, not both. Each measure is therefore assigned its own separate group of buildings without overlap. Table 12 compares the two measures considering savings figures per enrolled building.

Table 12. The two commercial air-conditioning measures compared

Parameter	AC setpoint raise (event-based conservation)	Pre-cooling (event-based load shift)
How it works	On a called event, the setpoint is raised by a fixed increment and held for the duration of the event.	The building is cooled below setpoint in the hours before the event. Once the event begins, cooling is cut back and the building relies on the already-cooled space.
Nature of the saving	Conservation	Load shift
Controls required	A controllable thermostat or basic building-management integration. No pre-event scheduling.	A building-management system that is capable of executing a scheduled pre-cool ahead of a called event.
Peak-demand reduction	1.20 kW per building	3.20 kW per building
Net energy saved	93.6 kWh per building per year	115.2 kWh per building per year

Results

For the 2.5 lakh household cohort, the assessment indicates the following results: For the 1.7 lakh building cohort, divided equally between the two measures, the assessment gives the following results:

Table 13. Commercial cohort results

Cohort	Buildings	Peak Reduced (MW)	Energy saved/Shifted (GWh/year)	Annual system value (INR cr/year)
AC setpoint raise	85,000	38.3	9.2	34.7
Pre-cooling	85,000	102.0	11.3	79.2
Combined portfolio	1,70,000	140.3	20.6	113.8

Table 14. Indicative commercial results for 1.7 lakh buildings

~126-154 MW Capacity saved in peak hours	~19-23 GWh Annual energy saved	~INR 102-125 cr Indicative gross annual system-level benefit
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A mere 5% of the commercial consumers are able to deliver 0.50% reduction in the forecasted state peak of 27,090 MW. Cohort-wise figures and the underlying assumptions on connected load, event duration, coincidence, and dependable-capacity factors are presented in the Appendix.

Most of the segment's savings is from avoided capacity, with energy and loss savings making up the remainder. That is the defining feature of commercial demand response, and the key point on which it differs from residential flexibility. These measures are dispatched only for the handful of hours in the year when the system is genuinely tight, so they buy firm peak capacity while barely touching the total units sold.

The capacity is also of a different quality. Commercial capacity is contractual because it is dispatched on instruction and metered against an event baseline. Therefore, it can be verified and counted in resource-adequacy planning, unlike behavioural response, which cannot be guaranteed in any given hour. That reliability is what makes the segment worth pursuing for DF measures even though its energy contribution is modest. The cost profile follows from the same logic. Buildings are paid through capacity and energy incentives for as long as they remain enrolled, so this is a running cost rather than a one-time equipment subsidy, and it grows with the number of events called. Considering the assumptions made here, the benefits exceed programme costs by a comfortable margin, with payback falling well inside the working life of the controls installed. Commercial Lifecycle Revenue Impact Measurement (LRIRIM) is -0.445% against a regulatory limit of INR 0.005/kWh, and Programme Administrator Test (PAC) Benefit to Cost Ratio is 1.581. The margin narrows if events are called more often than assumed, or if participating buildings prove less responsive than the coincidence and dependability factors assumed here.

Which measures to prioritise

Pre-cooling carries most of the capacity—almost 102 MW of the roughly 140 MW total and nearly three times the setpoint measure from the same number of buildings. But it is the harder of the two. It needs a building-management system that can run a scheduled pre-cool, and it returns little net energy for the capacity it provides. The setpoint raise is the simpler option: it needs only a controllable thermostat, produces genuine conservation with no catching up afterwards, and can be extended to a much wider set of mid-sized premises.

The practical approach is to phase the two rather than choose between them. The setpoint raise forms the broad base and is offered to as many commercial consumers as possible. Pre-cooling is concentrated in the better-equipped buildings that already have the controls. Done this way, most of the available capacity is captured while enrolment targets stay realistic.

4.2.3. Electric vehicles

Overview

In this analysis, EVs occupy a position different from the residential and commercial segments. In those segments the load already exists and the question is how much of it can be moved. Here, the load is still being built. Charging demand is entering the distribution system year by year as the fleet grows, and the utility has a short window in which to influence when that charging happens—, before charging habits settle around plugging in on arriving home in the evening, which is precisely when the system is least able to absorb it.

Table 15. EV segment: scale and scope

5,04,385 Total EVs registered in Tamil Nadu	10,000 EVs assumed for analysis	500 Charging stations assumed for analysis	3 hrs Peak hours charging per day	120 days DF days assessed per year
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Note: The above values are based on published sources and engineering references, validated through stakeholder consultations. They are not derived from a primary consumer survey.

The assessment considers 10,000 enrolled vehicles and 500 stations—a small share of the registered fleet and about a third of the public network. A vehicle stores the energy it draws, so charging can be moved in time without the owner losing anything, unlike cooling or hot water, where the service is consumed as it is delivered. . A vehicle parked overnight is connected for far longer than it needs to (for drawing power). Thus, potentially, there are several spare hours available that can be scheduled without any inconvenience. The other two segments do not offer so much room: a geyser has to deliver hot water within the hour, and a building has to stay comfortable while people are inside.

Which loads are flexible

In the case of EVs, two routes are available for DF measures: charging at home, which happens overnight and can be shifted with a controller, and charging at a public station, where the operator can throttle the rate on instruction.

Measures assessed

Two features of the segment determine the measures. The first is that charger power varies by vehicle type. A two-wheeler charger draws well under a kilowatt, while a car charger draws under 8 kW. The fleet is therefore segmented into two-, three-, and four-wheelers, each carrying its own charger rating, fleet share, and equipment cost, and the results are built up accordingly.

The second is that flexibility can be accessed through two quite different routes, and these are assessed as separate measures. Managed home charging reaches many small connections behind the consumer's meter and depends on a device installed at the premises. Managed public charging reaches a small number of large connections operated commercially, where a single instruction throttles several charge points at once. It is assumed that the two do not overlap: a vehicle charging at home is not simultaneously drawing charge from a public station.

Managed home charging

A controller or smart charge point shifts a vehicle's charging schedule out of the evening peak and places it for charging overnight, when the system is lightly loaded and generation is cheapest. The owner sets a departure time and the device decides when to draw power. Table 16 shows the assessment across the fleet, class by class.

Table 16. Managed home charging by vehicle class

Class	Charger (kW)	Fleet share	Vehicles	Energy shifted (kWh/yr)	Peak reduction (MW)	Annual system value (INR cr/yr)
Two-wheelers (E2W)	0.7	50%	5,000	227	1.8	1.9
Three-wheelers (E3W)	3.3	40%	4,000	1,069	6.6	7.0
Four-wheelers (E4W)	7.2	10%	1,000	2,333	3.6	3.8
All classes	—	100%	10,000	—	12.0	12.7

Two-wheelers constitute half the enrolled vehicles but provide only about 14% of the load reduction. Though many join, their chargers are simply too small to make much of a difference. It is the opposite with three-wheelers: fewer vehicles enrol but since their charger rating is high enough and their share in the fleet is large enough, they account for 55% of the measure's peak contribution. Four-wheelers deliver the most per vehicle by a wide margin but they cannot carry the programme alone and their equipment costs more per vehicle than what it does for the two-wheeler class.

Managed public charging

Public charging is accessed through the station operator rather than the vehicle owner. On a called event, the operator throttles output across the charge points at a site, reducing the draw without refusing service. Because a single station aggregates several high-powered points, the reduction per connection is large, of a magnitude higher than any individual vehicle. The agreement is with a business rather than a retail consumer, which makes calling and settling the response much simpler.

Table 17. Assumptions and key figures for managed public charging

Parameter	Value
Stations enrolled	500
Reduction per station on a called event	20 kW
Energy shifted per station	3,600 kWh/yr
Contribution to system peak	10.0 MW
Indicative annual value	INR 7.8 crore

As Table 17 shows, 500 public charging stations can provide a significant amount of flexibility by coordinating the charging of many EVs at once. Since these stations operate under a single point of control, the measure is easier to implement and verify—making them an alternative to manage peak electricity demand.

Results

Table 18. Indicative EV results

Metric	Indicative value
Capacity saved in peak hours	~20–24 MW
Annual energy saved or shifted	~10–12 GWh
Indicative gross annual system-level benefit	~INR 18–22 crore

EV charging does not use less energy. It uses the same energy at a different time. That is what makes this segment useful. The vehicles will draw the same units whenever they charge, and the entire question is whether those units land on an evening peak the system is straining to meet, or in the small hours when plant is idle. Shaped well, a growing EV fleet becomes a source of overnight load that improves plant utilisation. Shaped badly, it adds directly to the peak the state is already struggling to serve.

The timing argument is what distinguishes this segment from the other two. Residential and commercial flexibility is retrofitted onto habits and equipment already in place and must overcome them. EV charging behaviour is still forming. Making managed charging the habit while the fleet is small costs far less than winning the same behaviour back later, after a decade of unmanaged evening charging has been built into the demand curve.

Which measures to prioritise

Of the two measures, public charging appears more attractive because a relatively small number of charging stations can provide significant savings. However, participation may be more challenging. Many users choose public fast-charging because they value speed and may be willing to pay more for it. Any delay or reduction in charging speed could therefore make the service less attractive to users. This could also make charging operators less willing to participate, particularly if flexibility measures affect customer experience or revenue.

Home charging has none of these problems. The vehicle sits parked overnight, so charging can simply be pushed to a later time without the owner losing anything. It also saves more and its potential grows as the fleet grows.

Within home charging, it is worth targeting the right vehicles rather than more vehicles. Two-wheelers make up half of the enrolled vehicles but provide only about a seventh of the reduction. Four-wheelers give the most per vehicle; three-wheelers give the most in aggregate, and commercial fleets are easier to enrol because they are already run in groups.

So, starting with home charging makes the most sense, making it the default measure for new home chargers while the fleet is still small, and including public charging only where the operator is willing and the load is big enough to be worth it.

4.3. System-Level Benefits

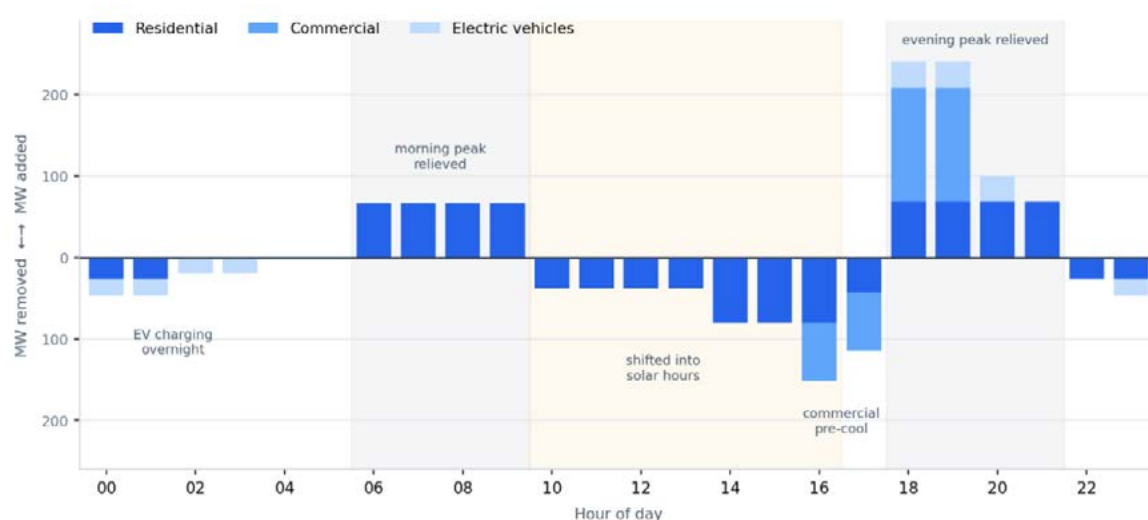
The three segments together

The three segments assessed in this analysis have been treated separately because the flexibility in each is obtained through a different means; for instance, a retrofit smart device in a household, a contract with a building operator, a controller on a vehicle charger. Read together, they act on the same grid but not in the same hours or in the same proportions. Commercial buildings supply most of the capacity at the evening peak, while households supply most of the energy across the day, and EVs contribute to both. That is why the three are assessed as a portfolio rather than measure by measure. The segment results show what to put in place. The portfolio view shows what the state gets in total.

How the load curve changes

The portfolio's value is not captured by a single number because the three sectors do not act at the same hour or in the same direction. Set out across the day, the programme makes four distinct movements. The energy removed from the two peak windows does not disappear; it reappears in the hours where the system has room for it.

Figure 3. Hourly footprint of the demand flexibility portfolio



Note: Bars above the line represent the load removed; bars below show the same energy reappearing elsewhere in the day. Shaded bands mark the two declared peak windows and the solar window.

Figure 3 shows how the programme changes demand through the day. Load is taken out of two busy windows and added to two quiet ones. The first movement is in the early morning, where geysers, pumps, and washing machines move out to the other hours. The second is the destination for that energy: the 10 a.m.–5 p.m. solar window, where it arrives as new midday demand at precisely the hours the state has the most generation and the least use for it. The third is the largest—the evening window, where commercial buildings, residential air conditioning, and delayed vehicle charging together remove a significant block of megawatts off the system peak, with commercial pre-cooling deliberately parking a portion of it in the late afternoon just before. The fourth is overnight, where vehicle charging settles into the small hours and adds load to the flattest part of the curve.

Taken together, the programme does not simply reduce demand; it moves demand from the hours the system finds expensive to the hours it finds cheap. Almost the same amount of energy is used over the day, but when it is used changes. That is a different thing from building generation and a considerably cheaper one.

What each segment contributes

Which segment matters most depends entirely on what parameter (capacity peak or energy saved) is being measured. At the evening-peak instance, commercial buildings deliver 61% of the reduction and households deliver 30%. However, if energy savings for the entire year are considered, households contribute 81% and buildings contribute 13%. This demonstrates that one segment cannot do another's job, thus highlighting the importance of assessing all three together.

Table 19. Share of relief at evening system peak

Commercial 61%	Residential 30%	EV 9%
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Table 20. Share of annual energy shifted

Residential 81%	Commercial 13%	EV 6%
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Commercial buildings provide most of the capacity but little of the energy shifted, because they are called on only for the few hours in the year only when the system is genuinely stretched. Households are the reverse: their controls work every day, so they give most of the energy but a smaller share of the capacity.

The measures and interventions across the segments should therefore go hand in hand. A utility that pursued only commercial flexibility would hold a valuable block of dispatchable capacity but would do nothing about the shape of the daily curve or about absorbing midday solar. A utility that pursued only residential flexibility would improve the curve and the solar balance but would have little to call on when the system is genuinely tight. The three together are worth more than the sum of the parts, precisely because no single segment can do both jobs.

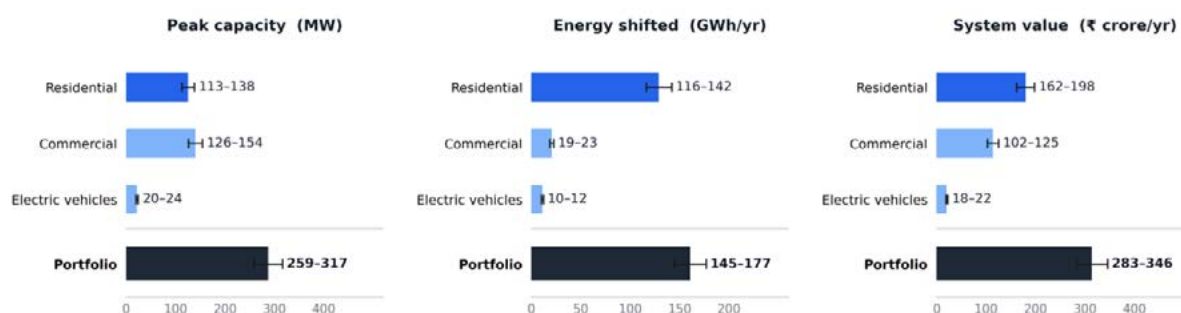
What the portfolio delivers

Because the system peak occurs once, while the sectors act in different windows, their contributions cannot be added across the day. When classified according to the peak windows, the portfolio delivers the following:

Table 21. Portfolio contribution classified by peak window

Segment	Morning peak, 6–10 a.m. (MW)	Evening peak, 6–10 p.m. (MW)
Residential	60–73	61–75
Commercial	—	126–154
Electric vehicles	—	20–24
All segments together	60–73	207–253

Figure 4. Segment-wise and portfolio contributions with uncertainty ranges



Note: Bars show the value the model returns; whiskers show the range around it.

The plus-or-minus 10% range in Figure 4 is based on the same set of assumptions applied to all three groups. So, the overall range is simply the three ranges added together.

The demand in Tamil Nadu reaches peak level in the evening. The residential, commercial, and industrial segments together offer approximately 205–255 MW at the evening peak—almost 1% of the forecast state peak of 28,500 MW—with a further 60–75 MW available in the morning window from the residential segment, which is the only one of the three segments that has it. Over the year, the three sectors together move something between 145 and 175 million units (MU) out of peak hours and return benefits worth about INR 290–355 crore to the system annually.



5. The Recommendation: A Phased Roadmap

Drawing on the findings of the literature review, cost-benefit assessment, and stakeholder consultations, our study proposes a phased roadmap for scaling up demand flexibility implementation in Tamil Nadu. The roadmap is designed to support a gradual and structured transition from small-scale pilot programmes to mainstreaming demand flexibility as a reliable resource in power system planning and operations.

Recognising that developing the technical, institutional, and consumer readiness required for large-scale implementation will take time, the recommendations have been organised in three phases. This phased approach would allow the state implementation agencies to build on early experience, address implementation barriers as they emerge, and progressively develop the regulatory, technological, and operational frameworks needed for large-scale deployment.

5.1. Phase I (0–3 years): Demonstrate and build capability

Objective: Establish proof of concept, generate pilot results that are specific to Tamil Nadu, and develop the institutional framework required for scaling up demand flexibility. In the first 3 years, the focus should be on launching a pilot, deploying low-cost automation technologies, and establishing monitoring, verification, and measurement protocols.

Launch targeted demand-flexibility pilots as proof-of-concept

Pilot programmes should focus on consumer segments that have the highest flexibility potential and the lowest implementation barriers, as identified in Section 4:

- **Residential:** prioritise the three measures identified in this study, which are: geyser-timer controls, air-conditioner pre-cooling, and washing-machine delay-start programs, using low-cost retrofit devices
- **Commercial:** target large commercial consumers (those with a demand above 100 kW), particularly Information Technology parks, shopping malls, hospitals, hotels, and universities in urban centres that are currently facing peak-demand stress.
- **Electric vehicles:** introduce managed charging pilots through public charging operators and commercial fleet operators, supported by default delayed charging for new home chargers and dedicated ToD tariffs.



Deploy low-cost residential automation

As smart-meter deployment continues to expand across Tamil Nadu, TNPDC should, in parallel, promote low-cost retrofit automation technologies such as smart plugs, geyser controllers, and smart switches for flexible residential appliances. These technologies provide an affordable way to residential consumers for early participation, while also building consumer familiarity and capability for wider adoption of demand flexibility.

Establish state-wide data system and measurement and verification framework

To use demand as a long-term and reliable system resource, the state must develop the required institutional capability, data systems, and the necessary measurement capabilities to identify, quantify, and manage flexible demand. As an initial step, the state should undertake baseline data mapping, using surveys to assess the extent of appliance penetration in households and the level of automation in commercial establishments. It should also identify feeders that are experiencing recurring peak stress to help target future programmes. In parallel, standard M&V protocols should be established to ensure that demand reductions can be consistently measured and validated.

5.2. Phase II (3–5 years): Scale up and integrate

Objective: Expand successful pilots into utility programmes and integrate demand flexibility into mainstream distribution planning. The focus must shift to expanding enrolment among the high-potential consumer segments, strengthening tariff signals to enable automated responses, and building an aggregation ecosystem so that smaller and distributed loads can also participate.

Scale up flexibility programmes for emerging loads through targeted enrolment

Expand enrolment among high-potential consumer segments, prioritising large commercial buildings, urban residential consumers with cooling loads, and EV-charging infrastructure.

Strengthen tariff signals

Enhance ToD tariffs to encourage electricity consumption during solar-rich hours while discouraging discretionary consumption during morning and evening peak periods. Tariff signals should increasingly work alongside automation, rather than relying solely on behavioural change.

Develop an aggregation ecosystem

Introduce a regulatory and operational framework for third-party aggregator participation. As most consumers cannot provide sufficient flexibility individually, TNERC should enable third-party aggregators to combine flexible demand from several smaller and geographically dispersed loads into larger, more predictable and dispatchable resources. Pilots can be introduced to test different aggregation models, assess consumer participation and retention, and determine costs of procuring aggregated flexibility.

Embed flexibility into new consumer connections

Where feasible, mandate new consumer connections to be automation-ready through the integration of smart meters, ToD tariffs, EV-ready charging infrastructure, and demand-response-compatible equipment. The state can work with retail stores and appliance manufacturers to increase awareness of smart devices and their long-term impact on energy savings.

5.3. Phase III (beyond 5 years): Establish demand flexibility as a core system resource

Objective: Integrate demand flexibility into long-term power system planning and electricity market operations. Here, TNERC and TNPDCCL must formally incorporate verified demand flexibility into resource adequacy assessments and move towards market-based procurement of flexibility services from aggregators.

Recognise demand flexibility in system planning

TNERC should formally recognise demand flexibility as a planning resource by incorporating demand response into resource adequacy assessments, distribution planning, and future procurement decisions.

Procure demand flexibility as a grid service

The state should transition from pilot programmes to market-based procurement of flexibility services. Distribution utilities should procure verified peak demand reductions from aggregators and other qualified providers through transparent mechanisms based on available capacity, verified reductions, and event-based performance.



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7. Appendix

7.1. Shared economic and system parameters

Table A1. Economic and system parameters common to the three segments

Parameter	Value	Unit	Source
Marginal power purchase cost, peak	10.0	₹/kWh	Data collected TNERC
Average commercial retail tariff	7.5	₹/kWh	Data collected TNERC
Avoided capacity cost	4.0	₹ crore per MW	Data collected TNERC
Annualised capacity value	66.5	₹ lakh per MW per year	Derived: CRF 0.16626 at 10.5% over 10 years
Distribution loss	10.41%	%	Data collected TNERC
Transmission loss	3.70%	%	Data collected TNERC
Discount rate, utility	10.5%	%	TNERC Tariff order
Discount rate, participant	13.0%	%	Assumed

7.2. Residential segment: Assumptions and cash flow

The study assumed a cohort of 2,50,000 households, with seven measures across six appliance categories. The enrolled households for each measure = the cohort multiplied by that appliance's ownership and participation rate.

Table A2. Appliance ownership, coincidence, and programme assumptions

Appliance	Assumed Ownership in cohort (%)	Assumed Coincidence factor	Households
Air conditioner	65.5	0.65	1,63,638
Water heater (geyser)	47.2	0.25	1,18,105
Washing machine	44.8	0.12	1,11,930
Water pump / motor	37.3	0.20	93,240
Refrigerator	85.0	0.40	2,12,402
Dishwasher	4.6	0.50	11,488

Note: The enrolment share is the proportion of the cohort assumed to own the appliance and join the programme; it is a programme assumption, not measured ownership across the state. Coincidence factors are engineering estimates of the share of enrolled appliances drawing power at the system peak

Table A3. Residential-measure-wise results

Measure	Type	kW/HH	kWh/HH	MW	MU/yr	Cost INR crore	Benefit INR crore
AC setpoint	Conservation	0.096	46	10.21	7.54	65.86	15.21
AC pre-cool	Shift	0.420	202	44.67	32.99	65.86	53.64
Geyser timer	Shift	1.200	438	35.43	51.73	3.40	61.09
Geyser setpoint	Conservation	0.400	73	11.81	8.62	8.15	17.48
Washing Machine delay	Shift	1.000	78	13.43	8.73	12.87	15.27
Pump solar	Shift	0.280	204	5.22	19.04	6.43	17.28
Pump VFD	Conservation	0.224	327	4.17	30.47	85.78	36.78
Fridge defrost	Shift	0.100	30	8.50	6.46	19.54	10.34
Fridge setpoint	Conservation	0.018	158	1.53	33.49	0.00	38.40
Dishwasher delay	Shift	1.400	218	8.04	2.51	1.32	7.17
Dishwasher eco	Conservation	0.360	62	2.07	0.72	0.40	2.18
Total				125.50	129.00	175.29	180.00

Table A4. Sample calculation for geyser timer control in residential sector

Parameter	Calculation	Result
Load reduction per home	Rated power 2.0 kW × 60% of use falling at peak	1.20 kW
Energy per home per year	2.0 kW × 1 hour/day × 365 days × 60%	438 kWh
Households enrolled	2,50,000 × 47.2% enrolment share	1,18,105
Peak reduction	1.20 kW × 1,18,105 × 0.25 coincidence ÷ 1,000	35.43 MW
Annual energy	438 kWh × 1,18,105 ÷ 1,000,000	51.73 MU
Energy benefit	51.73 MU × ₹6.50/kWh × 1.1162 loss componnet	₹37.53 cr
Capacity benefit	35.43 MW × ₹0.665 cr per MW	₹23.56 cr
Total benefit	₹37.53 cr + ₹23.56 cr	₹61.09 cr

7.3. Commercial segment: Assumptions and cash flows

Assumed cohort of 1,70,000 buildings, divided equally between two non-overlapping measures. A building is enrolled in one or the other, never both.

Table A5. Commercial measure assumptions, per enrolled building

Parameter	AC setpoint raise	Pre-cooling
Buildings enrolled	85,000	85,000
Connected AC load	8.0 kW	8.0 kW
Demand reduction factor	0.15	0.40
Peak demand reduction, gross	1.20 kW	3.20 kW
Event duration / events per year	2 hrs / 60	2 hrs / 60
Gross event-window energy	93.6 kWh/yr	384.0 kWh/yr
Recovery factor	-	0.70
Net energy saved at the meter	93.6 kWh/yr	115.2 kWh/yr
Coincidence factor	0.50	0.50
Dependable capacity factor	0.75	0.75
Firm peak contribution	38.3 MW	102.0 MW
Equipment cost	₹5,800	₹6,600
Annual O&M	₹400	₹550
Capacity incentive	₹50/kW/month	₹50/kW/month
Energy credit	₹3.0/kWh dispatched	₹3.0/kWh dispatched
Enrolment credit / admin / marketing	₹1,500 / ₹800 / ₹500	₹1,500 / ₹800 / ₹500

Note: Equipment cost and enrolment credit are one-time costs incurred in Year 1; all other costs/incentives are applicable annually.

Table A6. Commercial-measure-wise results

Cohort	Buildings	kW per building	kWh per building/year	Peak MW	Energy GWh	Value INR cr
AC Setpoint Raise	85,000	1.20	93.6	38.25	9.22	34.66
Pre-Cooling	85,000	3.20	115.2	102.00	11.35	79.18
Total	1,70,000	—	—	140.25	20.57	113.84

Table A7. Sample calculation for AC set-point temperature control in commercial buildings

Parameter	Calculation	Results
Load reduction per building	8.0 kW AC load × 15% demand reduction (1.5 °C × 10% per °C)	1.20 kW
Energy per building per year	8.0 kW × 9.75% (1.5 °C × 6.5% per °C) × 2 hrs × 60 events	93.6 kWh
Firm peak reduction	85,000 × 1.20 kW × 0.50 coincidence × 0.75 dependability ÷ 1,000	38.25 MW
Energy at the meter	85,000 × 93.6 kWh ÷ 1,000,000	7.96 GWh
Energy at the generation bus	7.96 GWh × 1.1591 loss uplift	9.22 GWh
Energy benefit	9.22 GWh × ₹10.00/kWh	₹9.22 cr
Capacity benefit	38.25 MW × ₹0.665 cr per MW	₹25.44 cr
Total benefit	₹9.22 cr + ₹25.44 cr	₹34.66 cr

7.4. Electric vehicles: Assumptions and cash flows

10,000 enrolled vehicles across three classes, plus 500 managed public charging stations. The two measures address separate load — enrolled vehicles charge at home, and the stations serve other vehicles.

Table A8. EV programme parameters

Parameter	Home charging	Public stations
Charge rating	0.7/3.3/7.2kW by class	25 kW per point, 4 points per station
Flexible hours	3 hrs/day	2 hrs per event
Days / events per year	120 flexibility days	90 events
Share charging at peak	0.50	0.40
Throttle depth		0.50
Station configuration		4 points × 25 kW
Average draw	0.90	
Reduction per station		20 kW

Table A9: Assumptions and results by class

Class	Charger rating	Fleet share in the cohort	Units	Energy shifted (kWh/yr each)	Peak (MW)	Value (INR crore/year)
E2W	0.7	50%	5,000	227	1.75	1.86
E3W	3.3	40%	4,000	1,069	6.60	7.02
E4W	7.2	10%	1,000	2,333	3.60	3.83
Public stations	20 kW/station	—	500	3600	10.00	7.76
Total					21.95	20.46

Table A10. Sample calculation for home-charging electric vehicles

Parameter	Calculation	Result
Energy per vehicle per year	$3.3 \text{ kW} \times 0.90 \text{ average draw} \times 3 \text{ hrs} \times 120 \text{ days}$	1,069 kWh
Vehicles enrolled	$10,000 \times 40\% \text{ fleet share}$	4,000
Peak reduction	$4,000 \times 3.3 \text{ kW} \times 0.50 \text{ coincidence} \div 1,000$	6.60 MW
Energy at the meter	$4,000 \times 1,069 \text{ kWh} \div 1,000,000$	4.28 GWh
Energy at the generation bus	$4.28 \text{ GWh} \times 1.1591 \text{ loss uplift}$	4.96 GWh
Energy benefit	$4.96 \text{ GWh} \times ₹5.30/\text{kWh spread}$	₹2.63 cr
Capacity benefit	$6.60 \text{ MW} \times ₹0.665 \text{ cr per MW}$	₹4.39 cr
Total benefit	₹2.63 cr + ₹4.39 cr	₹7.02 cr

Cost-effectiveness test results

Each measure is assessed against three standard tests: the participant test (PCT), the programme administrator test (PAC) and the rate impact measure expressed as life-cycle revenue impact (LRIRIM), which must not exceed INR 0.005/kWh. All measures have cleared the PCT. Also, the residential programme is funded through a one-time equipment contribution rather than recurring incentives, so a benefit–cost ratio is not directly comparable. Viability is assessed on net present value, which is positive across the assessment period.

Table A11: Segment-wise PAC and LRIRIM test results

Segment and measure	PAC BCR	LRIRIM
Commercial: AC Setpoint Raise	1.360	–0.094%
Commercial" Pre Cooling	1.704	–0.350%
Commercial: Combined	1.581	–0.445%
EV: Managed home-charging	1.138	–0.002%
EV: Public charging stations	2.274	–0.047%

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